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LANDSLIDES AND SURFACE BREAKS OF THE 1911 M_S 8.2 KEMIN EARTHQUAKE (*Kyrgyzstan*)

D. Delvaux, K. E. Abdrakhmatov*, I. N. Lemzin*, and A. L. Strom**

Royal Museum for Central Africa, B-3080 Tervuren, Belgium
** Kyrgyz Institute of Seismology, Asanbai 52/1, Bishkek, 720060, Kyrgyzstan*
*** Gidroproekt Institute, Volokolamskoe shosse 2, Moscow, 125812, Russia*

The 1911 M_S = 8.2 Kemin (Kebin) earthquake in the northern Tien Shan (Kazakhstan, Kyrgyzstan) formed a complex system of surface ruptures nearly 190 km long and numerous landslides and rock avalanches up to tens of millions of cubic meters in volume. Judging from their distribution, six fault segments of the Kemin-Chilik and the Aksu fault zones with different strikes, dips, and kinematics were activated. The Kemin earthquake was one of the strongest events of a sequence of seismic catastrophes that affected the Kungei and Trans-Ili-Alatau mountain ranges between 1887 and 1938. The effects of the Kemin earthquake are well documented in a monograph published soon after the event by K. I. Bogdanovich. In the framework of the European INCO-COPERNICUS program, the surface ruptures, landslides, and rockslides associated with this earthquake have been re-examined in detail. In addition, the large-scale tectonic setting of the Kemin-Chilik and Aksu fault zones has been re-evaluated, and their segments have been identified and described. The whole system forms a sinistral transpressional structure, which controls the formation of the mountain ranges between the Issyk-Kul' depression and the Kazakhstan block. The surface ruptures of the 1911 earthquake can presently be observed in the field over a total length of nearly 100 km and generally reactivate longer-term cumulative paleoseismic fault scarps. The presence of well-expressed paleoseismic fault scarps and several tremendous ancient landslides in the Chon-Kemin, Chon-Aksu, and Aksu valleys can be considered as evidence for strong prehistoric earthquakes.

Active fault, landslides, 1911 Kemin earthquake, Tien Shan, Kyrgyzstan

INTRODUCTION

The 1911, M_s 8.2 Kemin earthquake occurred along the Chon-Kemin-Chilik fault zone, at the interaction between the Kazakhstan platform and the Tien Shan fold belt. It was part of a sequence of strong earthquakes, starting with the 1887, M_s 7.3±0.5 Verny earthquake near Alma-Ata [1, 2], and followed shortly by the 1889, M_s 8.3 Chilik [3], the 1911, M_s 8.2±0.3 Kemin (Kebin) [4], and the 1938, M_s 6.9±0.5 Kemin-Chu earthquakes [5, 6]. The last three marked an east-to-west propagation of stress release along the Chon-Kemin-Chilik fault zone (Fig. 2). The Kemin earthquake killed 452 and injured 740 people [4]. The number of casualties was relatively low for such a strong earthquake, because it affected mainly mountainous areas of the Kyungei-Alatau and Trans-Ili-Alatau Ranges, between Lake Issyk-Kul' and Alma-Ata (formerly Verny). It generated surface ruptures along several fault segments and caused landslides, rockfalls, debris flows, and secondary soil dislocations over a total area of 10,000 km^2, 200 km long and 70 km wide, elongated parallel to the fault zone [4, 7].

The surface effects of the 1911 Kemin earthquake were investigated beginning a few months after the event by an expedition led by K. I. Bogdanovich in spring 1911 [4]. This team explored the mountainous area affected by the earthquake, mainly by horses, following the major valleys. They mapped and described all the observed surface deformations and differentiated primary effects, of postulated tectonic origin, from secondary

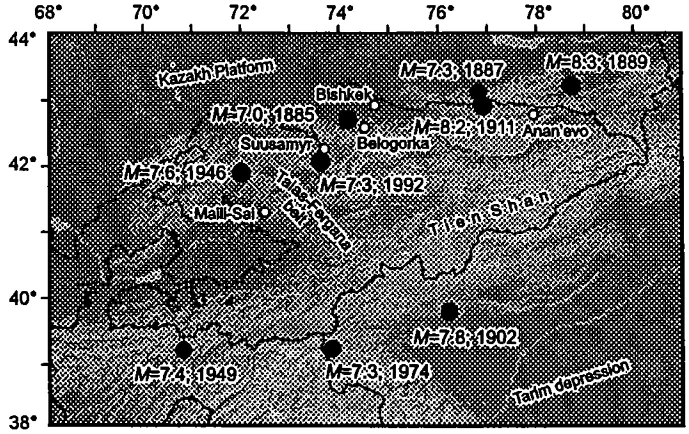

Fig. 1. General location of Kyrgyzstan with the epicenters of the strongest earthquakes.

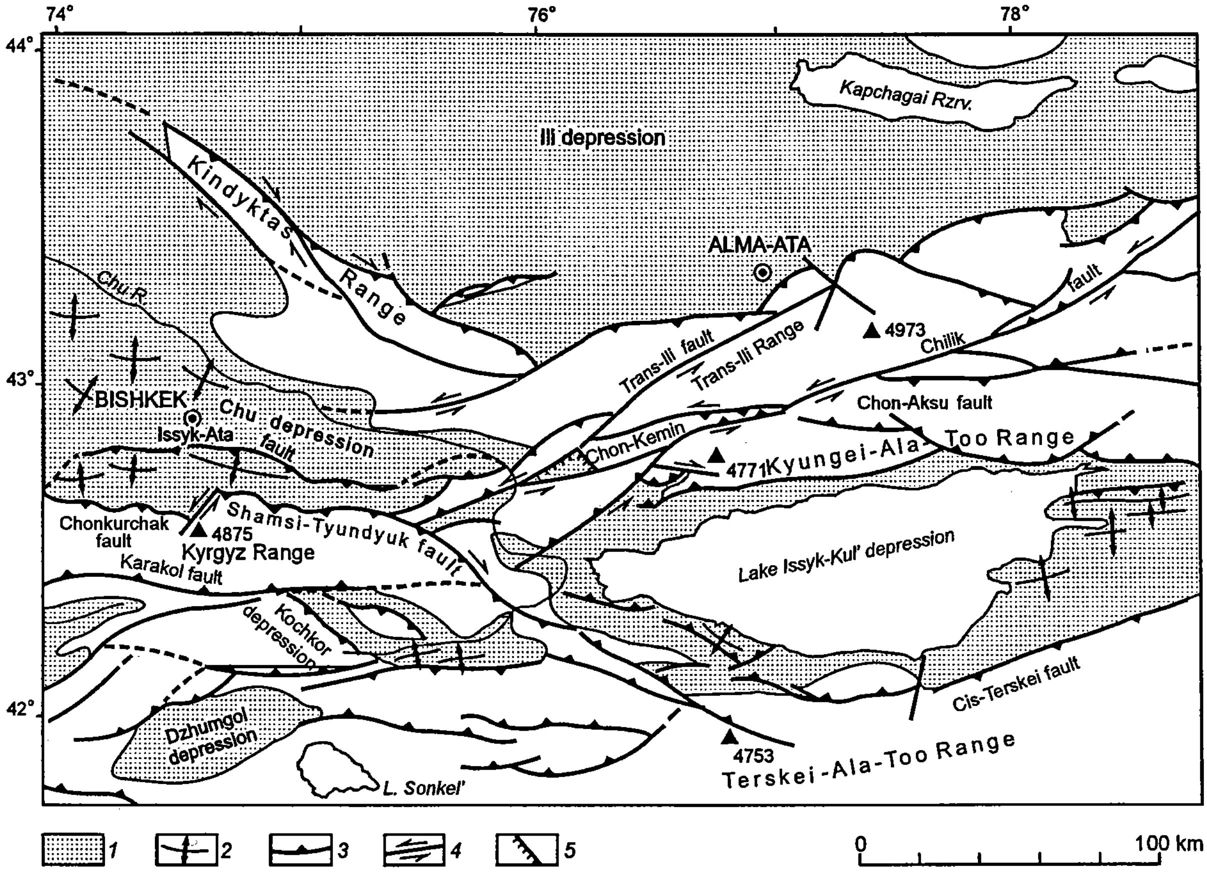

Fig. 2. Neotectonic structure of the Issyk-Kul' depression and Chon-Kemin fault zone in the Kyungei- and Trans-Ili-Alatau Ranges [25]. ***1*** **— Cenozoic depressions;** ***2*** **— anticlines within depressions;** ***3*** **— upthrusts and thrusts;** ***4*** **— shifts;** ***5*** **— faults.**

effects not directly related to faulting. They distinguished ruptures without displacements from ruptures with displacements. The latter are considered the effects of movements associated with faulting at depth. The explorers also characterized the movements as either vertical or lateral, or a combination of both. They gave a seismotectonic interpretation to the primary effects only when they coincided with observable tectonic lines.

To follow Bogdanovich et al. [4], geologists visited the area for regional geological mapping, but no further detailed investigations were performed on the seismotectonic expression of the Kemin earthquake. Only Kuchai

[8, 9] reinspected some of the surface deformations with the aim to compare them with the descriptions and photographs made by Bogdanovich et al. [4]. In the framework of a European Community INCO-Copernicus project, we revisited the area several times between 1996 and 2000. We intended to perform reconnaissance mapping of the presumed 1911 surface ruptures, to refine their precise relationship with longer-term paleoseismic fault scarps, and to recognize the possible segmented nature of the fault zone. The geometry and kinematics of individual fault segments were characterized, and special attention was paid to the landslides supposedly triggered by the 1911 event. Some active faults were selected for further studies by paleoseismology, topographic levelling, and geophysical profiling. The detailed results will be presented elsewhere. This paper presents an overview of the system of explored active faults and related recent and ancient seismic dislocations.

GEOLOGIC SETTING

The modern Tien Shan Range is an active intracontinental mountain belt in Central Asia that has been developing between the Tarim and Kazakhstan plates since the Miocene [10–12]. It is characterized by a high degree of seismic and tectonic activity.

The Tien Shan was intensely reactivated in the Tertiary, following the India-Eurasia collision [13, 14]. Sedimentation, compressional deformation, and unroofing started in the Late Oligocene [11, 15–18] or in the Middle Miocene [16, 19, 20] and were active about the time of the Tertiary-Quaternary transition [21]. Preliminary paleostress investigation indicated that the Paleogene and Neogene deformation was the result of a compressive stress field with N-S horizontal principal compression [11, 18]. The present-day stress field is still characterized by N-S compression [22–24]. The map of active faults of the Kyrgyz Tien Shan has been recently compiled by Abdrakhmatov et al. [25]. The present rate of N-S overall shortening across the Tien Shan is estimated at ~20 mm/year on the basis of GPS measurements in Kazakhstan, Kyrgyzstan [12], and China [26].

The Chon-Kemin fault is part of the Chon-Kemin-Chilik fault zone sinistral transpressional zone (Fig. 2) that was active probably since the Late Pliocene, reactivating a Late Paleozoic-Mesozoic fault zone [27]. It controls the structure of the whole range between the Issyk-Kul' depression and the Kazakhstan Shield and forms the active boundary between the Tien Shan and the Kazakhstan plates. It balances dextral strike-slip movements along the NW-oriented Talas-Fergana and other faults. The neotectonic structure and active faults of the Trans-Ili-Alatau Range in Kazakhstan have been reviewed by Tibaldi et al. [28, 29]. Chedia et al. also [30] detailed the structure of the junction between the Kyungei-Alatau and the East Chu depression.

FAULT SEGMENTATION

The surface ruptures related to the 1911 M_s 8.2 Kemin earthquake appear to be distributed along a series of alignments which are interpreted as various fault segments. Each segment is characterized by particular orientation, inclination, and kinematics. The segments are clearly differentiated from each other on the basis of these parameters. A total of six segments were identified (Fig. 3). They will be briefly described below, from west to east. The boundaries of some segments are tentative, though the change of orientation and/or kinematics along the fault can be caused by cross-cutting disturbances.

Let us briefly run through the terminology used. Active faults are long-lasting disturbances the movements along which took place at the recentmost stage of evolution as well. The topographically expressed Late Quaternary (Q_{III-IV}) and modern (in our case, of 1911) surface ruptures are treated as ancient and modern seismotectonic dislocations, respectively. In some cases, such ruptures are observed along the entire length of the fault, e.g., along the Chon-Aksu segment (see below). But seismic dislocations can be displayed as a discontinuous line, which in total is shorter than the active segment of the fault. For example, during the M_s = 7.3 1992 Suusamyr earthquake in Kyrgyzstan, the surface ruptures were observed for as little as 4 km at two isolated segments separated by a 20 km long span [31].

When mapping the surface ruptures and fault segments, we differentiated (1) the surface ruptures mapped by the team of Bogdanovich soon after the 1911 earthquake, (2) surface ruptures that could be seen during our field work between 1996 and 2000, and (3) longer-term morphotectonic fault scarps, issued from repeated paleoseismic movements since the Middle or Late Pleistocene. Not all paleoseismic dislocations were revived in 1911, and, on the contrary, some recent surface ruptures have no direct indications of preceding displacements. It seems reasonable to relate some of the ruptures not described earlier to the 1911 dislocations, because they are distinctly expressed in the present-day topography and demonstrate a virtually complete morphological similarity to the Kemin earthquake ruptures [4].

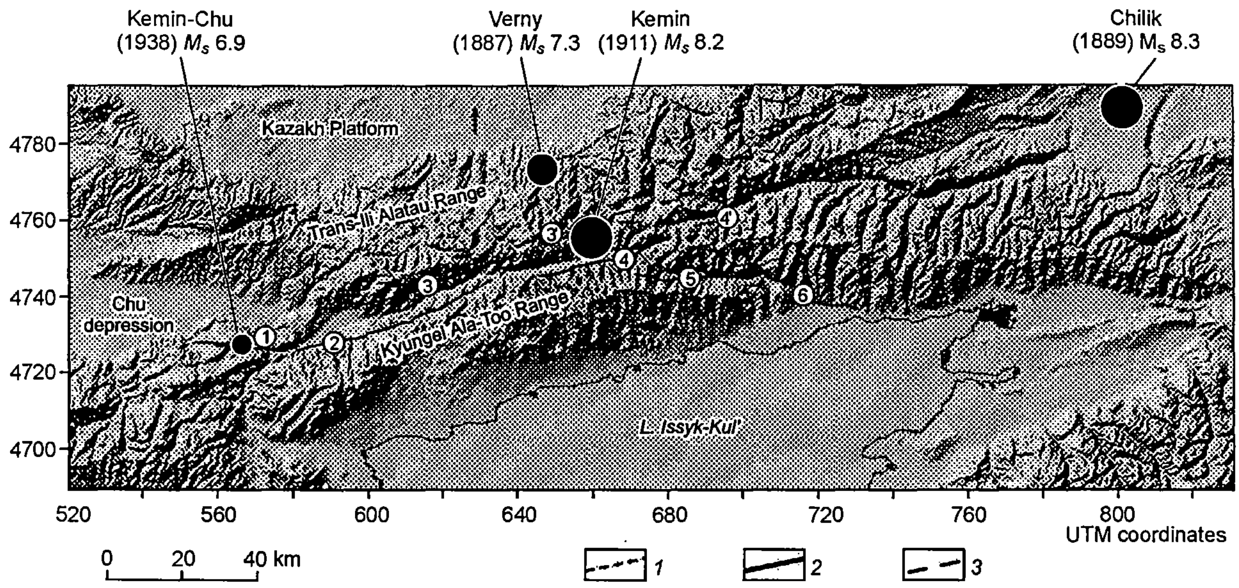

Fig. 3. Surface ruptures of the 1887 Verny and 1911 Kemin earthquakes, compiled from 1:200,000 scale map [4]. 1 — supposed position of seismogenic rupture caused by the 1887 Verny earthquake [4]; 2 — seismogenic ruptures caused by the 1911 Kemin earthquake, after [4] and our data; 3 — supposed position of segments of the 1911 ruptures. 1–6 — different fault segments activated by the 1911 Kemin event: 1 — Dzhil'-Aryk, 2 — Lower Chon-Kemin, left bank, 3 — Lower Chon-Kemin, right bank, 4 — Upper Chon-Kemin-Chilik, 5 — Chon-Aksu, 6 — Aksu.

Dzhil'-Aryk fault segment. The westernmost segment activated by the 1911 event lies near the junction of the Chu and Chon-Kemin Rivers. It runs along the narrow local depression separating the pericline of the West Kyungei uplift from the Ortotokoi block of the Kyrgyz Range [11] (Fig. 4). It crosses the Chu valley just before the river junction, where it has displaced the Middle Pleistocene channel of the Chu River by 10–15 m (southern block uplifted relative to the northern one). It then continues westward at the foot of the slope, along the railroad, and passes above the railroad itself, where it juxtaposed Paleozoic red sediments over the rounded pebbles of a Pleistocene terrace.

The general trend of the segment is E-W, but it is relatively curved in plan. The minor fault planes observed at the outcrop are 45 to 60° south-dipping, with a predominant dip-slip movement. Limited lateral movements seemed to have also occurred along steeper planes. The lateral movements are also inferred from the interpretation of airborne images, but their sense and amount cannot be determined accurately. In conclusion, the Dzhil'-Aryk segment can be considered a south-dipping reverse fault, with possible limited lateral movement.

Bogdanovich et al. [4] mapped about 10 km of surface ruptures related to the 1911 earthquake along this segment. The neotectonic expression of this fault segment is approximately 20 km long. At present, the 1911 ruptures cannot be clearly differentiated from the rest of the fault scarps. This segment is close to the epicenter of the 1938, M_S 6.9 Kemin-Chu earthquake, but it is not clear whether or not it was reactivated during that event [5, 6].

Eastward, the fault runs along the lower canyon-like part of the Chon-Kemin valley and then joins the Lower Chon-Kemin left-bank segment of the Kemin-Chilik faulting zone. The boundary between them is conventional.

Lower Chon-Kemin fault segments. The lower part of the Chon-Kemin valley, between Dzhaya and the Chon-Kemin depression, is flanked by active faults on both sides (Fig. 4). They constitute the Lower Chon-Kemin left-bank segment and the Lower Chon-Kemin right-bank segment, respectively. To the west, they are connected to the Chon-Kemin depression. The latter lies between the Kyungei Range and the Chon-Kemin massif and forms a downfaulted basin, with a structure resembling that of a pull-apart basis. It contains Tertiary sediments, now largely covered with Pleistocene alluvial and loess deposits.

The two Lower Chon-Kemin fault segments are parallel to each other, trending WSW-ENE and displaying a left-lateral component of movement together with a dip-slip component. They should therefore be classified

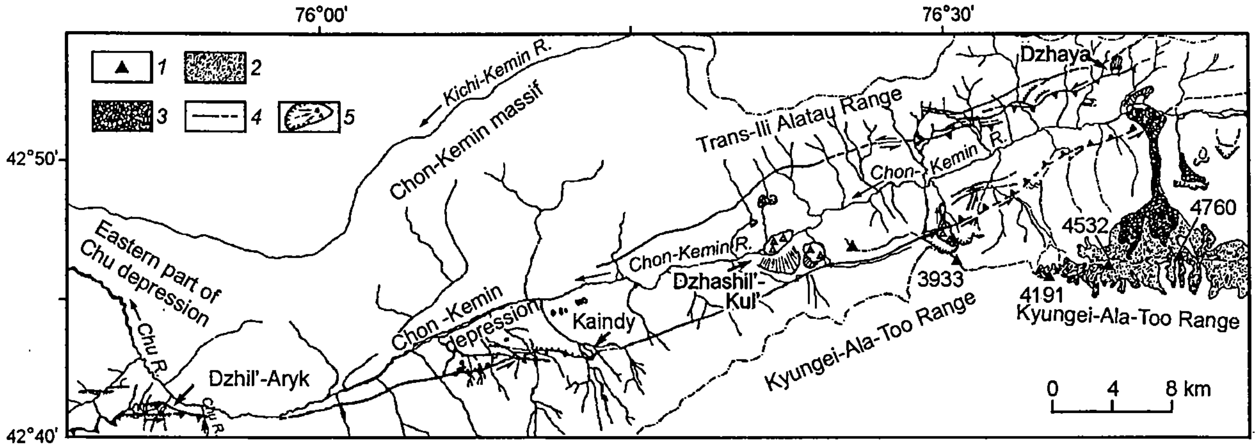

Fig. 4. Surface ruptures and longer-term paleoseismic fault scarps along the lower Chon-Kemin valley, with distribution of the largest landslides (related to the 1911 event and older ones). 1 — peaks (m), 2 — glaciers, 3 — late Pleistocene morains, 4 — young ruptures, 5 — scarps.

as oblique-slip. They represent two steeply dipping faults in a sinistral transpressional zone, with the central corridor going upward (expulsed) between the two faults. It is not known whether the two segments join at depth to a single fault zone. If so, they could form a positive flower structure.

It is possible that the two segments were activated during the Kemin earthquake in a kind of left-stepping relay zone. The surface ruptures are best expressed on the western extremity of the southern segment (left bank) and seem to be transferred to the northern segment (right bank), farther eastward.

Lower Chon-Kemin left-bank fault segment. On the left bank of the Lower Chon-Kemin valley (southern side), Bogdanovich et al. [4] recognized up to 48 km of surface fault ruptures. They affect the southern margin of the Chon-Kemin depression, pass right in the scarp of the Kaindy landslide, then they are followed in the high mountains behind Dzhachik-Kul', near Lake Kel-Kogur, and continue eastward up to the point marked 3933 m in Fig. 4.

The general trend of the surface rupture is ENE-WSW trending, and the fault plane is subvertical to steeply dipping. On the margin of the Chon-Kemin depression, the plane is supposedly steeply north-dipping, with a normal component of movement in addition to a marked left-lateral component. About 2 km west of the Kaindy landslide, two small river streams crossing the fault scarp are displaced laterally to the left, by 40 and 20 m, respectively. This represents obviously cumulative displacement and illustrates well the long-term left-lateral component of movement along this segment.

East of the Kaindy landslide, the surface rupture can no longer be seen either in the aerial photographs taken in 1988 or in the field. It apparently disappeared rapidly because of solifluxion processes, whose typical structures are visible in aerial images. However, farther eastward, south of Lake Kel'-Kogur, the rupture is distinctly visible in the satellite and aerial images. It is very likely that the 1911 seismodislocation inherits topographically expressed traces of older movements.

Upstream, near Dzhaya, no surface ruptures related to the 1911 earthquake are reported [4], but a paleoseismic fault scarp, 10–30 m high, is well expressed. It is almost entirely submerged under a late Pleistocene moraine descending from the Kyungei-Ala-Too Range. The fault scarp then obliquely crosses the Chon-Aksu valley and probably continues in an ENE direction. The moraine deposit itself is affected by a discrete scarp, seen mostly on airborne images but difficult to see in the field. The moraine is likely related to the last glacial advance, and therefore might correspond to the Q_{III}^2 stage (20–15 ka). This means that the slip rate is very low on that portion of the fault and that most of the slip was acquired before 20 ka. In this area, the fault plane seems steeply north-dipping to subvertical, and the northern compartment is moving up relatively to the southern one. A significant left-lateral component can also be deduced from the river channel network.

Considering the portion of the fault segment activated during the 1911 event and the Dzhaya portion, a total extent of 62 km long is obtained for the Lower Chon-Kemin left-bank segment.

Lower Chon-Kemin right-bank fault segment. Along the right bank of the Lower Chon-Kemin valley (northern side), only 2 km of surface ruptures were mapped by the team of Bogdanovich, near Dzhaya. More precisely, this was the only portion of the fault that could be seen from the bottom of the main valley. On the basis of interpretation of aerial images, digital topography, and field surveys, we found that the fault trace can be followed laterally over more than 20 km along lateral valleys, between 2500 and 3100 m altitude (Fig. 4). A recent rupture is particularly well expressed along a paleoseismic fault scarp, with several lateral branches. We suspect that this fault system is continuing westward, up to the Chon-Kemin depression, affecting the northern flank of the Chon-Kemin valley. To the east, it probably obliquely crosses the Trans-Ili-Alatau Range in an ENE direction, toward Kazakhstan.

Along this fault segment, the southern block is constantly displaced upward relative to the northern one. The fault plane is subvertical to steeply inclined, alternating between north-dipping portions with a normal component of movement and south-dipping portions with a reverse component. These lateral variations along trend are typical of a strike-slip fault. Along the fault segment, we found local evidence for 5–10 m left-lateral slip and 4–5 m vertical displacement during the last event. The last movement along this fault segment might have occurred in 1911, although Bogdanovich has reported only 2 km of surface ruptures. However, we can imagine that they simply did not study this fault in detail as it was rather difficult of access and could not be seen from the valley.

About 18 km of surface ruptures were mapped in the field, with the help of aerial images, and the total potential length of the fault segment on the northern slope of the Trans-Ili-Alatau Range (in Kyrgyzstan) is about 40 km. Another 40 km might exist on the southern slope of the Trans-Ili-Alatau Range (in Kazakhstan).

Recent and prehistoric landslides. A great many landslides in the Neogene-Quaternary deposits in the southern part of the Chon-Kemin depression and collapses on steep rock scarps have occurred in the explored part of the pleistoseist zone of the Kemin earthquake. The largest, Kaindy, rockslide of about 8–10 mln m^3 in volume lies immediately on the path of a seismogenic rupture related to the left-bank segment.

Several large Pleistocene rockslides are known along the lower Chon-Kemin valley. The first group of three landslides occurred in the Dzhashil-Kul' area. A large landslide body (150–200 mln m^3) dammed the valley. It comes from the southern slope, affecting greenschist facies metasediments. These were transported downward and now lie partly against the granitic northern flank of the valley. Two other smaller landslides occur in lateral valleys.

In Dzhaya, a large rockslide of 20–25 mln m^3 is known along the trace of the right-bank fault segment. In the middle of the Chon-Kemin valley, another landslide with a highly curved shape of the rupture scarp also dammed the valley. Its body lies partly over the terminal Q_{III}^2 moraine of the glaciers coming from the Kyungei Range. A C^{14} AMS dating of a paleosoil over the moraine deposit, preserved under the landslide body, gave 6190±160 years (alkali fraction) and 6660±420 years (residue fraction). This corresponds to 7000–8000 years calibrated age (Early Holocene). This landslide was previously believed to be older than the moraine itself [32]. The relation between the two can now be better observed owing to recent excavations for the road.

Upper Chon-Kemin-Chilik fault segment. Discontinuous surface ruptures totaling 46 km were mapped by Bogdanovich in the upper part of the Chon-Kemin valley, above Dzhaya, and in the upper part of the Chilik valley (Figs. 3 and 5). They are distributed over a total length of 66 km, defining the Upper Chon-Kemin-Chilik fault segment. We had no opportunity to visit the upper reaches of both valleys, and only 3.5 km of possible surface ruptures could be seen on the 1988 aerial images.

In his monograph [4], Bodganovich indicated a series of secondary ruptures and landslides in the upper part of the Chon-Kemin valley. Several landslides can be seen on aerial images. It also seems that several moraine deposits were remobilized, damming the valley at two points and isolating a lake between them.

Chon-Aksu fault segment. The Chon-Aksu fault segment is almost E-W and could be traced from the Aksu pass to the Kok-Bel' pass (Figs. 3 and 5). It terminates eastward in the Aksu valley, maybe against a transversal tear fault. To the west, it probably continues across high mountains and glaciers, but its possible connection with the Upper Chon-Aksu valley is unclear.

About 20 km of surface ruptures along this segment were described by the Bogdanovich team [4]. In their report, they mention that they were stopped in their progression upstream along the Chon-Aksu valley near the second lake. We went further in the upper part of the valley and could follow the surface expression of the fault over 12 km, up to the Aksu pass. The total length of mapped surface rupture is therefore at least 32 km, while the potential length of the fault segment is 40 km, considering the western termination of the segment, after the Aksu pass.

Careful observation of the active fault scarp, preliminary trenching, and direct observation of the fault plane in a deep gorge show that this segment has a typical reverse faulting character, with a 60° north-dipping

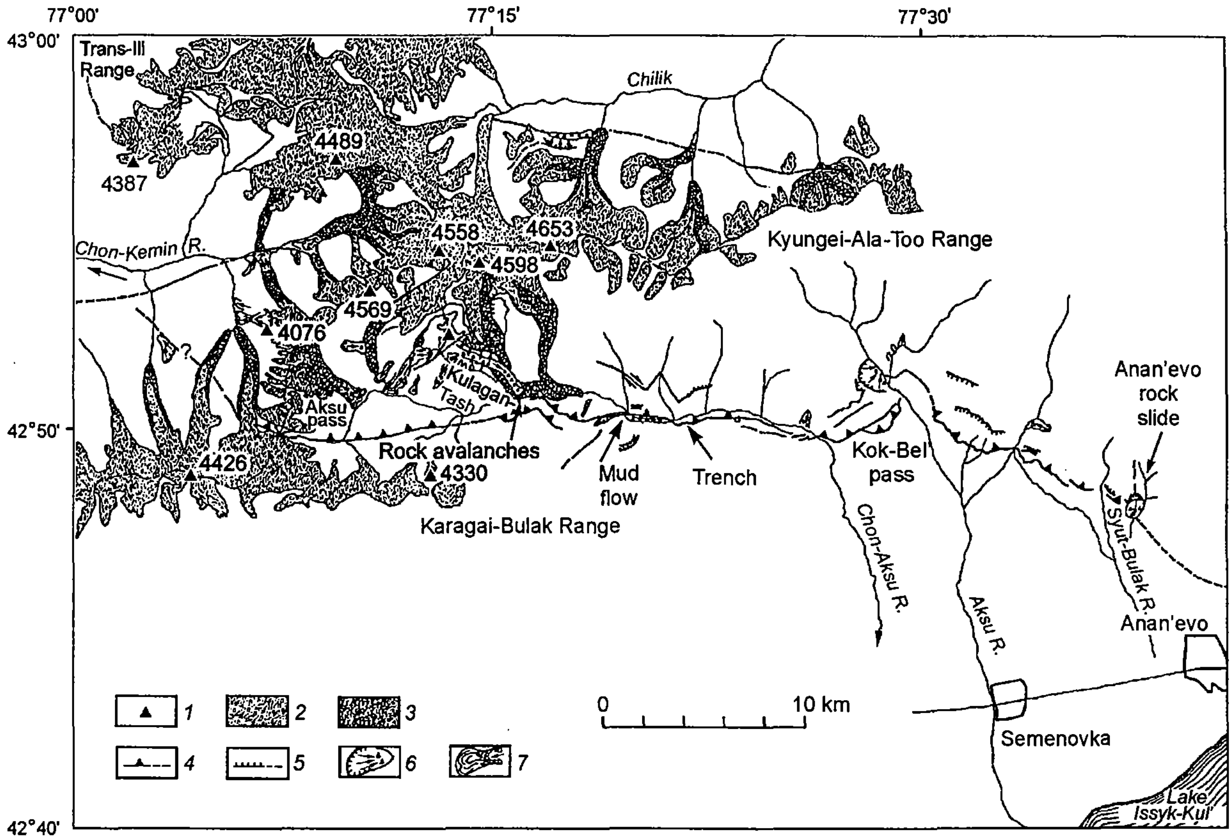

Fig. 5. Surface ruptures and landslides of the 1911 Kemin earthquake in the upper Chon-Kemin, Chilik and Chon-Aksu valleys. 1 — peaks (m), 2 — glaciers, 3 — late Pleistocene moraines, 4 — main surface ruptures (upthrusts and thrusts), 5 — feather joints, 6 — scarps, 7 — active moraines.

fault plane. The fault scarp associated with the 1911 event reaches locally 8–10 m in height but more generally between 4 and 6 m. The maximum height of 10.5 m was reported in [4]. Observation of displaced river thalwegs showed that the lateral component, if any, did not exceed 1 m.

Landslides and mud flows. Several rather unusual mass movements were observed along this segment, which were not reported by Bogdanovich et al. [4]. Two large rock accumulations cover Late Pleistocene moraine deposits along the northern flank of the valley in its upper part (Fig. 5). One of them occurs in the Kulagan-Tash valley (the Valley of Fallen Stones in Turkic). They can be interpreted as rock glaciers or eventually as rock avalanches. They are very recent, as the surface of the debris is very fresh and covered only with very small lichens (1–2 cm in diameter). They were probably caused by large rock falls from collapsing walls of steep glacial valleys on active glaciers and related moraines. The rock masses came from altitudes of around 4000 m, accumulated on glacial valleys at around 3600–3700 m altitude, and flowed downward to the middle of the Aksu valley, at 3000–3100 m high. The landslide bodies amount to 20 to 40 mln m^3.

In the intermediate part of the Chon-Aksu valley, the alluvial plain is now covered with a large debris flow over a distance of 2.2 km. It originated from a massive Middle Pleistocene moraine accumulation on the southern side of the valley. In the moraine, there is now a 200 m large, 100 m deep, and 1500 m long trench, not seen on the picture taken by the Bogdanovich team a few months after the 1911 earthquake. It is however present on the 1956 aerial photos. It therefore formed several months or years after the main shock. This moraine is located along the trace of the active fault and was destabilized by the surface deformations related to the 1911 event. Progressive water infiltration in open fractures probably caused the debris flow. The flow moved in a catastrophic way, the largest blocks being supported in a fluid mud matrix. It stripped away all the trees along its way and partly dammed the valley. The mass of the debris flow is estimated at 15 mln m^3.

Aksu fault segment. The Aksu fault segment is trending WNW-ESE, from the Aksu River to Lake Issyk-Kul', behind Anan'evo Village (Figs. 3 and 5). This is the most accessible fault segment, for which

Table 1

Length of Surface Ruptures and Fault Segments Activated by the 1911 M_s 8.2 Kemin Earthquake

Segments	Length, km, after [4]	Length of faults (km) observed during field work and related to 1911 earthquake			Total length of fault zone segment, km
		total	after [4]	not described earlier	
Dzhil'-Aryk	9	9	9	0	20
Lower Chon-Kemin, left bank	48	20	20	0	62
Lower Chon-Kemin, right bank	2	18	2	16	40(80)
Upper Chon-Kemin-Chilik	46	3.5	3.5	0	66
Chon-Aksu	20	32	20	12	40
Aksu	34	14	14	0	34
Total	159	96.5	68.5	28	262 (302)

Bogdanovich et al. [4] reported up to 34 km of surface ruptures. The surface deformations diminish in intensity to the east, and surface expression becomes discontinuous. Now, only 14 km of surface ruptures are still observable on the western half of the segment.

The highly sinuous trace of the fault scarp and its relation to the topography suggest that the fault surface is gently dipping to the north. It probably becomes steeper at depth. The vertical displacement reaches a maximum of 3–5 m on the western half of the segment and decreases progressively to the east. This fault segment can be classified as a north-dipping thrust at the subsurface.

The 1911 Kemin earthquake triggered several relatively large landslides in the mountainous areas and numerous secondary soil dislocations along the margin of Lake Issyk-Kul'. Some of them were apparently important as shown by the pictures published in [4]. The most important landslide occurred near Anan'evo (~15 mln m^3). It affected highly weathered granite, with the scar situated above the seismogenic fault. It was selected for a detailed study of the seismogenic triggering mechanism.

TOTAL RUPTURE LENGTH

The lengths of the six fault segments activated by the 1911 Kemin earthquake are summarized in Table 1.

It is evident that most of the surface ruptures observed by Bogdanovich et al. [4] could no longer be observed during field survey and on the aerial images. However, we reported new ruptures, possibly associated with the 1911 event. This suggests that the surface expression of the active faults can disappear rapidly and that the survey made by the team of Bogdanovich was incomplete.

The Bogdanovich team mapped the surface ruptures a few months after the event, so their record can be considered relatively accurate for the areas directly surveyed during their expedition. However, the geographic location is generally not precise because of their rough topography. It was difficult to restore their observations accurately on the modern topographic maps.

LANDSLIDE DISTRIBUTION AND HAZARD

Numerous landslides and rock avalanches up to tens of millions of cubic meters were associated with the 1911 Kemin earthquake. The presence of several tremendous ancient landslides in the Chon-Kemin and the Chilik valleys can be considered indirect evidence for strong prehistoric earthquakes in the studied zone.

The analysis of landslide distribution along the Chon-Kemin and Chon-Aksu valleys revealed that a large concentration of landslides of different types and volumes occurs along the trace of surface fault ruptures. All these seem to occur in heavily fractured rocks in a zone of weathering [33]. A group of large rock slides, supposedly triggered by the Kemin earthquake, occur in a high-altitude area, at the headwaters of the Chon-Aksu River, in the hanging wall of an active reverse fault. Some large 1911 landslides are near the Aksu thrust. The most voluminous ones (200 mln m^3) are of Late Pleistocene – Early Holocene age. The most recent ones are related to the 1911 Kemin earthquake, as mapped by Bogdanovich et al. [4].

Since most of the landslides along the Chon-Kemin and Chon-Aksu valleys are likely of seismic origin, landslide hazard mapping should also take into consideration the probabilistic seismic hazard of the area and the recurrence time for strong earthquakes. Paleoseismological work has been undertaken along the Chon-Aksu fault, aimed at determining the recurrence interval and slip rate of the Chon-Aksu fault segment. Much more paleoseimological work has to be performed on the various segments of the Chon-Kemin fault zone before a complete paleoseismic history can be inferred.

CONCLUSIONS

In conclusion, the M_s ~8.2, 1911 Kemin earthquake caused a minimum of 188 km of surface ruptures and activated six different segments. The surface ruptures are distributed among the six segments which belong to the Chon-Kemin-Chilik fault zone. The segments were activated along different trends, E-W, ENE-WSW (predominant), and WNW-ESE. The subsurface expression of the active fault segments ranges from south-dipping reverse fault at the western extremity (Dzhil'-Aryk segment), to north-dipping thrust fault at the eastern extremity (Aksu segment). Though there are no detailed data on the easternmost, Chilik, segment, the other faults of ENE strike running along the Chon-Kemin valley are characterized by considerable, up to 5–10 m, sinistral displacement, which developed under transpression with a subordinate (no more than 3 m) vertical component and alternating normal and reverse movements, depending on the rupture dip. On the contrary, the faults of the Aksu zone are dominated by vertical displacements of 3 to 8 m (possibly, to 10.5 m), with a negligible horizontal component. Thus, we can state that the 1911 Kemin earthquake was triggered by a mutual offset of some blocks separated by oppositely oriented faults with different kinematics. The possibility of triggering such a complicated system of disturbances during one earthquake may require a revision of the estimates of the highest possible magnitudes of earthquakes based on the idea that the earthquake foci are confined to particular quasihomogeneous segments of neotectonic structures (faults).

Further investigation of the Chon-Kemin fault zone is necessary in order to better assess its cumulative seismic and landslide hazard, including reconnaissance mapping of remotely accessible parts, assessment of rock slides and rock avalanches or rock glaciers in the 1911 Kemin event, and detailed paleoseismological work along the different segments of the Chon-Kemin fault zone for detailed characterization of their parameters (slip rate, recurrence time, faulting history, kinematics).

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