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Short Note

Ground-Truth Locations for the Mangyshlak Peaceful Nuclear Explosion Sequence, Western Kazakhstan

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Abstract The Mangyshlak peaceful nuclear explosion (PNE) sequence consisted of three detonations in western Kazakhstan in 1969 and 1970. Although ground-truth (GT) locations for peaceful nuclear explosions (PNEs) conducted in the former Soviet Union are generally thought to be well known, they can be erroneous by up to tens of kilometers, and the Mangyshlak sequence is no exception. We identified collapse craters for the first two events using Google Earth satellite imagery. A candidate location for the third event was determined using a cluster analysis location routine for the relative location with respect to the known collapse craters. All three locations were confirmed as GT-0 locations by site visits. Relative to previously published and accepted coordinates for the three Mangyshlak PNEs, our locations differ by 2.3, 6.7, and 15.7 km, respectively.

Introduction

The accurate and precise determination of hypocenters is important for seismological and nuclear monitoring purposes. In general, however, earthquake hypocenters are not accurately determined, making explosions a critical asset in the calibration of travel-time curves due to their known coordinates and origin times. From 1965 to 1988, exclusive of weapons testing in Novaya Zemlaya, and Kazakhstan, 122 peaceful nuclear explosions (PNEs) were detonated across the former Soviet Union (Sultanov *et al.*, 1999), including 64 in and near Kazakhstan (Fig. 1). The Mangyshlak series consisted of three detonations in southwestern Kazakhstan in 1969 and 1970, approximately midway between the Caspian and Aral Seas (Sultanov *et al.*, 1999; Mangyshlak-1 on 6 December 1969, Mangyshlak-2 on 12 December 1970, and Mangyshlak-3 on 23 December 1970; hereafter abbreviated as Man-1, Man-2, and Man-3, respectively) either for the purpose of creating collapse craters for water reservoirs or as the initial experiments for a new nuclear test site (Nordyke, 2000; Podvig, 2001). The Man-1 and Man-2 PNEs are reported to have produced surface collapse craters following detonation, whereas Man-3, being deeper, did not (Nordyke, 2000). The Mangyshlak PNEs were among the largest in terms of explosive yield and seismic magnitude (Man-1 30 kt, 5.8 m_b; Man-2 80 kt, 6.0 m_b; and Man-3 75 kt, 6.0 m_b; Sultanov *et al.*, 1999). The seismological community has generally accepted location coordinates for the PNEs as tabulated by Sultanov *et al.* (1999) even though they indicate that 43 of the events do not meet their ground-truth (GT)-1, that is, accurately known to within 1 km, criteria. In Sultanov *et al.* (1999), Man-1 and Man-3 are listed as GT-1, whereas Man-2 is listed with a seismically determined location presumed to be of GT-5 or GT-10 quality.

Revision of Ground-Truth (GT) Locations

An examination on Google Earth of the locations reported by Sultanov *et al.* (1999) for the Mangyshlak sites fails to confirm the presence of collapse craters or other clear evidence of PNE detonations. Man-1 and Man-2 are in nondescript locations in the desert, whereas Man-3 appears to coincide with an animal watering hole at the center of many radial paths that is similar to other features common in the area.

A closer survey of the surrounding landscape, however, does reveal two apparent collapse crater structures, one 2.3 km west of the Sultanov *et al.* (1999) location for Man-1 and one 6.7 km north of the Sultanov *et al.* (1999) location for Man-2 (Fig. 2). The collapse structures were identified by topography and general appearance of the structure on the satellite imagery. Both collapse structures are several meters deep and show what appear to be localized radial cracks as well as weakly visible collapse structures around the edges of the depression. There is no similar collapse structure in the vicinity of the Sultanov *et al.* (1999) location for Man-3.

That neither collapse structure is within 1 km of any previously indicated location leads to two conclusions. First, the presumed GT-1 or better accuracy of Sultanov *et al.* (1999) for the Man-1 location is in error. Second, it is not clear which collapse structure corresponds to which PNE.

Figure 1. Peaceful nuclear explosions (PNEs) in the vicinity of Kazakhstan. The Mangyshlak sequence location is noted.

The correct association of the craters becomes more confusing when considering published comments on which Mangyshlak PNEs generated collapse craters. Podvig (2001) states that no collapse crater was created by Man-2, thus if this information is correct, the southern collapse crater, based on distance alone, would associate with Man-1 and the northern with Man-3. Nordyke (2000) indicates that it was Man-3 that did not generate a collapse crater, which further confuses the association of events to craters. Nevertheless, the northern collapse structure is approximately 400 m in diameter and the southern 200 m in diameter. Presumably, the smaller southern crater would be associated with the smaller PNE, which is Man-1 at 30 kt, and the larger crater with either Man-2 or Man-3 at 80 and 75 kt, respectively. Nordyke (2000) lists the depth of Man-3 as 740 m, with a greater scaling depth relative to the yield than Man-1 or Man-2, and this may be justification for assuming that there was no collapse crater from Man-3.

To associate two of the Mangyshlak PNEs with the correct collapse craters and obtain a general location for the third, we conducted a multiple-event relocation analysis with three explosions to determine their relative locations. The relocation was done with a version of the hypocentroidal decomposition method (Jordan and Sverdrup, 1981) that has been highly developed for application in calibrated location studies (e.g., Walker *et al.*, 2011). This analysis was done using a merged dataset of phases and picks from the local and regional Soviet networks as well as those available from the International Seismological Summary. For the relocations, the parameters from Sultanov *et al.* (1999) were used as a starting point (stars in Fig. 3). The two xs near Man-1 and Man-2 are the locations of the two collapse craters identified in Google Earth. The solid vector shows how the relative locations of the events changed during the first part of the relocation, in which all available readings were used to estimate improved relative locations but only teleseismic P arrivals (using the ak135 velocity model) to establish the absolute location. To match the relative locations of Man-1 and Man-2 to the collapse crater locations, the cluster is shifted about 8 km east-northeast, which is the dashed vector for each event. The confidence ellipses for the seismically determined relative locations have semimajor axis lengths of 300–400 m (90% confidence level). There is an additional component of uncertainty that is related to the estimation of the absolute coordinates of the cluster, that is, the association with the collapse structures. In this case, that additional uncertainty is approximately 500 m, and when the two components are added, the uncertainty of the location of any individual event is about 600 m at the 90% confidence level.

The relative locations allow us to say with certainty that the northern collapse crater is associated with Man-2 and the southern with Man-1. The identification of the collapse craters allows us to assign GT-0 locations to both Man-1 and Man-2 with confidence (Table 1) and to ascribe errors to the Sultanov *et al.* (1999) locations. The error for the Man-2 location is 6.7 km, which is consistent with the Sultanov *et al.* (1999) estimate. The error for the Man-1 location, however, which was assigned a confidence of GT-1 or better, is actually 2.3 km.

The Sultanov *et al.* (1999) location for Man-3 is assigned a confidence of GT-1 or better, but that is not consistent with the new calculated location, which is significantly to the south. The fit to the seismic data and associated relative location with respect to the Man-1 and Man-2 locations restrict the location of Man-3 to be within about 1 km of the

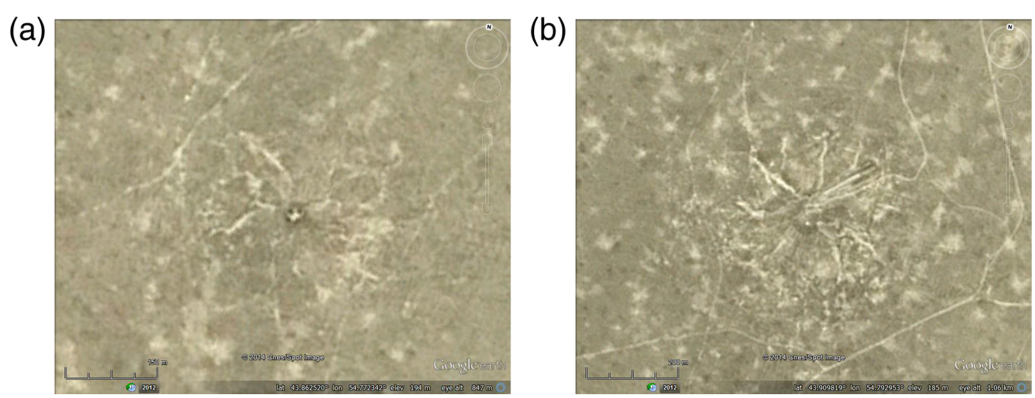

Figure 2. Google Earth (CNES/Spot) images of collapse craters associated with (a) Man-1 and (b) Man-2. The color version of this figure is available only in the electronic edition.

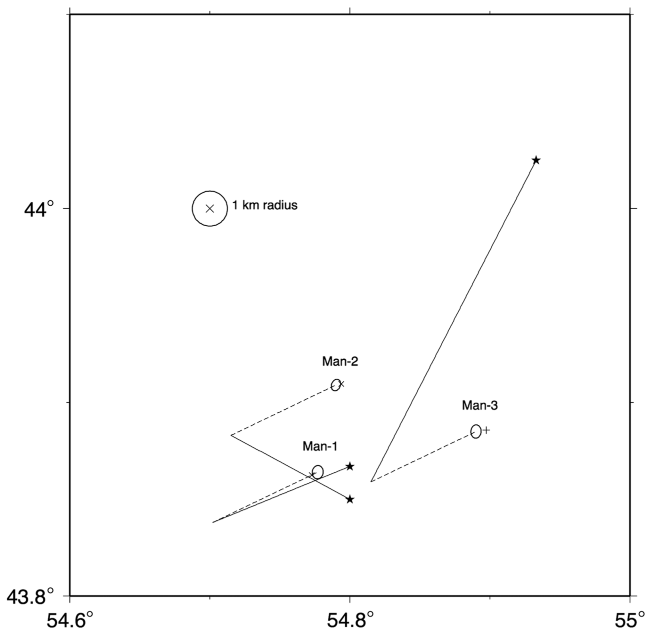

Figure 3. Relocations of the Mangyshlak PNEs. The original Sultanov *et al.* (1999) locations are indicated by stars; they were used as the starting locations in the relocation analysis. The solid black lines indicate the changes in relative locations in the relocation analysis. The absolute locations are biased because teleseismic *P* arrivals and a standard 1D global travel-time model were used to establish the absolute coordinates of the cluster. The dashed lines represent the single correction vector (7.0 km at N64°E) needed to achieve the best fit of the cluster to the Man-1 and Man-2 collapse craters shown by the x's. The plus sign marks the Global Positioning System coordinates for Man-3. The ellipses represent the relative location uncertainty for each event, at the 90% confidence level. When the uncertainty of the calibration process (i.e., the shift that brings the cluster into closest agreement with the two collapse structures) is included, the uncertainties of the seismic locations are approximately twice as large (~600 m) as shown in the figure. A circle of 1 km radius is shown for scale.

calibrated location. Based on apparent disturbed ground that is similar to the appearance of other PNE detonation sites, we choose a location approximately 300 m east from the Man-3 calibrated location as a possible detonation site and a candidate site for field verification. The relative location calculations were a tool used for site identification prior to fieldwork and were not evaluated with respect to refinement of event origin times or improving location procedures in the region.

In July 2013, an expedition was undertaken to field verify the three Mangyshlak PNE sites. The collapse craters from Man-1 and Man-2 are prominent in the field, and both are surrounded by an extensive network of encircling fractures outside the collapse crater. The Man-1 site is quite clean, and the specific borehole sites are not apparent in the bottom of the crater (Fig. 4a). At the Man-2 site, the presumed central borehole is entombed in a concrete block about 3 m square, and one nearby instrument borehole is open. The borehole sites are surrounded by a rectangular trench and berm in the bottom of the collapse crater (Fig. 4b). The Man-3 site was easily identified on the ground by the presence of several large boreholes. The borehole sites are surrounded by a rectangular trench and berm in the same manner as Man-2 (Fig. 4c). Rocks dropped down one of the open instrument boreholes result in distinctive splash sounds, indicating that the instrumentation and likely the nuclear detonation was emplaced below the water table. The Global Positioning System (GPS) coordinates taken in the collapse craters are within 50 m of the Google Earth determined coordinates. This small level of discrepancy is well within the practical limits of precision in use by the nuclear monitoring community for designation as GT-0 location accuracy. The location of Man-3 was coincident with the candidate site identified just east of the relative location determination. The difference between seismically determined location coordinates and the GPS coordinates of the borehole is about 490 m.

Conclusions

The GT-0 locations of the three Mangyshlak PNEs have been determined through comparison of the pattern of relative locations from a multiple-event relocation analysis with the pattern of two collapse craters identified from satellite imagery. The geometries of the spatial patterns make the association of specific shots with specific collapse structures unambiguous. The GT location of the third event, for which no collapse structure was visible in the satellite imagery, was confirmed by a site visit that was guided by the seismically determined location. The locations determined in this study represent significant corrections to the locations for these events in Sultanov *et al.* (1999) and also carry significantly lower uncertainties.

Figure 4. (a) Collapse crater from Man-1. (b) Collapse crater and infrastructure at the Man-2 site. (c) Borehole locations for Man-3 (photo by Alek Abishev).

Table 1
Revised Ground-Truth (GT) Coordinates for the Mangyshlak Peaceful Nuclear Explosion (PNEs)

PNE	Site Visit GPS Coordinates		Sultanov *et al.* (1999) Coordinates		Difference (km)	Proposed GT
	Latitude (° N)	Longitude (° E)	Latitude (° N)	Longitude (° E)		
Mangyshlak-1, 6 December 1969	43.8625	54.7727	43.867	54.800	2.3	GT0
Mangyshlak-2, 12 December 1970	43.9096	54.7937	43.85	54.80	6.7	GT0
Mangyshlak-3, 23 December 1970	43.8858	54.8973	44.025	54.933	15.7	GT0

The use of GT or calibrated events in seismology is expanding as they are appreciated as sources of high-quality reference data for a variety of seismological research topics. PNEs are especially useful in this regard, if their locations can be adequately calibrated, because they typically occurred in regions that are lacking in natural seismicity and therefore provide valuable raypath coverage for studies of the Earth's velocity and attenuation structure.

Because of their importance as reference events it is vital that proposed GT events be carefully validated whenever possible, especially as new data sources and technologies for analysis become available. Therefore, the improvement of GT databases is a continuous process that is not limited to adding new events; it is equally important to revisit these datasets and confirm locations. It is likely that the locations of additional PNEs can be validated at useful levels of accuracy with continued research of the sort we have employed here.

Data and Resources

The International Seismological Summary (ISC) data catalog at http://www.isc.ac.uk/iscbulletin/search/bulletin/ was searched (last accessed September 2011). Additional phase data were obtained from a 2001 unpublished report compiled by the Geophysical Survey, Russian Academy of Sciences.

Acknowledgments

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Queries

1. AU: Please note that in figure 2, left and right have been changed to part labels (a) and (b), respectively.