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7.5 Onset time estimation and location of events in the Khibiny Massif, Kola Peninsula, using the Analyst Review Station

Introduction

The technique of intelligent post-processing of seismic events proposed by Kværna and Ringdal (1993) has been shown to give a substantial improvement in location accuracy when applied to seismic events in the Khibiny Massif, Kola Peninsula. In this paper, we compare the performance of the analyst using the Analyst Review Station (ARS) to these results. As part of this study, we estimate the uncertainty in analyst time picks for phases from various regional arrays (see Fig. 7.5.1), and we discuss the implication of these uncertainties in terms of the resulting effect on location accuracy. An important conclusion inferred from this work is that, in many cases, location accuracy does *not* improve when adding new phase readings and applying current location programs.

The Khibiny Massif events

Six apatite mines are located within an area of about 10 km^2 in the Khibiny Massif on the Kola Peninsula of Russia (see Fig. 7.5.2). A detailed description of these mines and the mining activity is found in Mykkeltveit (1992). Although we have no explicit information on the exact sizes of these mines, interpretation of various maps suggests that the typical size is about 1 km^2. The Kola Regional Seismological Centre has since the beginning of 1991 provided NORSAR with information on mining blasts in the six Khibiny Massif mines. Detailed information on the 58 events used in this study is given in Kværna (1993).

Kværna (1993) investigated the potential automatic use of an onset picker based on autoregressive likelihood estimation. Both a single-component version and a three-component version of this method were tested on data from events located in the Khibiny Massif, recorded at the Apatity array, the Apatity three-component station and the ARCESS array. Using this method, he was able to estimate onset times to an accuracy (standard deviation) of about 0.05 s for P-phases and 0.15-0.20 s for S-phases. He noted that these accuracies are as good as the best analyst picks, and considerably better than the accuracies of the current onset procedure used for processing of regional array data at NORSAR.

Estimating the precision of manual onset time picks

As reported by Kværna (1993), P and S onsets at two stations in Apatity, APA0 and APZ9, and the Pn onsets at ARCESS were manually picked using the interactive EP program (Fyen, 1989). Given the fact that the characteristics of the Khibiny Massif events were known, the manual phase picking was considered to be done under "optimum conditions". By "optimum conditions" we mean that the analyst utilized information on the approximate phase arrival times and looked for typical signatures of the different phases. He also selected filters and seismometer components so as to obtain the highest SNR.

For the purpose of the study reported in this paper, all events were reviewed by another analyst using the Analyst Review Station (ARS) of the IMS. This analyst made time picks for available phases for four arrays (NORESS, ARCESS, FINESA, APATITY) as well as for the APZ9 station. We consider the phase picks from the ARS to be obtained under so-called "operational conditions" and they may therefore be less precise than those obtained under "optimum conditions". This is due to the fact that ARS is used as a tool for routine analysis (i.e., relatively short time spent on each pick) of large quantities of data and that the analyst did not have readily available information on the characteristics of the Khibiny Massif events.

Following Sereno (1990), an unbiased estimate of the measurement variance is determined from the arrival time difference between two phase observations for repeated events in the same mine.
Specifically:

$$\sigma^2_{1,pick} + \sigma^2_{2,pick} = \frac{\sum_{k=1}^{N_{mines}} \sum_{i=1}^{N_{obs}} [\Delta T_{obs_{ik}} - \langle \Delta T_{obs} \rangle_k]^2}{(N_{obs} - N_{mines})} \qquad (1)$$

where σ_1^2 and σ_2^2 are the picking variance of each phase, $\Delta T_{obs_{ik}}$ is the ith observation of the arrival time difference for the kth mine. $\langle \Delta T_{obs} \rangle_k$ is the mean arrival time difference for the kth mine. N_{obs} is the total number of observations (at all mines), and N_{mines} is the number of mines.

Kværna (1993) used formula (1) in various combinations to estimate standard deviations of time picks for various phase types and stations. He found that the P-phase at APA0 could be picked with a precision of $\sigma = 0.04$ seconds when the pick was made by the analyst under "optimum conditions". In the present study, we will use these P-times (for APA0) as reference, and we will assume that their standard deviation $\sigma_{2,pick}$ is 0.04. In this way, we can estimate $\sigma_{1,pick}$ directly from (1) for each mine, and average these data over the six mines (using the number of events as a weighting factor) to obtain overall estimates of the uncertainty.

Results

The resulting estimates of the precision in time picks by the analyst, using the ARS station, are presented in Table 7.5.1 and Figs. 7.5.3-7.5.4.

Fig. 7.5.3 shows the results for the Apatity array APA0 and the 3-component station APZ9. The array has a better precision for P phases (0.05 versus 0.08), probably because of a far better P-wave SNR (see Table 7.5.1). However, the 3-component station has more precise S and Rg estimates, probably because of their more impulsive nature compared to the array recordings. Note that these secondary phases have a far lower accuracy in the time picks than the P-phases. Also note that for the P and S phases the ARS analyst picks are not as precise as the automatic time picks presented by Kværna (1993).

Fig. 7.5.4 shows the results for Pn, Sn and Lg at the three arrays ARCESS, FINESA and NORESS. Pg for ARCESS is also shown. Not unexpectedly, Pn has the most precise picks, followed by Sn and Lg. The ARCESS Pn has by far the best precision. This is reasonable in view of the very high SNR for these phases (Table 7.5.1). Note also that for FINESA and NORESS it is possible to read phases for only about half of the events or fewer.

The much larger uncertainty in FINESA and NORESS P-precision compared to ARCESS (about 0.8 versus 0.09 seconds) is noteworthy. Clearly, the location program ought to take this difference into account and weigh the data accordingly. At present no routine mechanism for doing such weighing is applied in the IMS system, although the option to do so exists.

Location results

Figs. 7.5.5-7.5.7 show plots of event locations obtained under three different scenarios. All location estimates have been made with an assumed 0 km depth.

Fig. 7.5.5 shows the location provided by the automatic IMS system with no analyst review. All the arrival times used here are taken directly from the SigPro processing, and are thus subject of significant uncertainty. The median location error is 10.6 km, which must be considered excellent for a fully automatic system. Some "outliers" are due to occasional erroneous phase identification by the automatic system.

Fig. 7.5.6 shows the results after applying intelligent post-processing to the ARCESS and Apatity arrays. The median error is now 1.9 km and the worst case error is 5.9 km.

Fig. 7.5.7 shows the results after using the analyst (ARS) reviewed data in the location procedure. The median error is 3.3 km, and the worst case error is 14.5 km. These results are much better than the automatic IMS processing, but not as good as for the intelligent post-processing.

As shown by Kværna (1993), the ARS picks for the Apatity stations and ARCESS are not quite as good as the intelligent post-processing picks. A slight degradation in location accuracy must therefore be expected. Nevertheless, we consider that a main reason why the ARS locations do not match those of the intelligent post-processing is the inclusion of NORESS and FINESA readings in the data base, without appropriate weighting. We plan to pursue this problem further in the future.

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Table 7.5.1 (2 pages)

ARCESS

	N	σ	SNR
Pn	57	0.087	52.9
Pg	53(1)	0.647	5.8
Sn	57	0.563	4.1
Lg	57	1.13	5.4

FINESA

	N	σ	SNR
Pn	23	0.781	5.00
Sn	28	1.465	2.67
Lg	33	2.149	3.46

NORESS

	N	σ	SNR
Pn	22	0.854	6.21
Sn	13	1.290	3.02
Lg	12	3.360	2.81

APATITY ARRAY (APA0)

	N	σ	SNR
Pg	58	0.051	57.60
Lg	58	0.389	8.43
Rg	57	0.494	8.59

APATITY 3-COMPONENT STATION (APZ9)

	N	σ	SNR
Pg	58	0.080	15.20
Lg	58	0.184	7.79
Rg	57	0.254	8.89

Table 7.5.1. Basic data corresponding to Figs. 7.5.3 and 7.5.4. The entries in the tables are:

N : Number of phases analyzed (outliers in parantheses)

σ : Estimated standard deviations (s) of ARS time picks

SNR : Geometric average of the linear signal-to-noise ratio (STA/LTA) of the N phases. SNR of non-detections have been set to 3.5 for P-phases and 2.5 for S-phases.

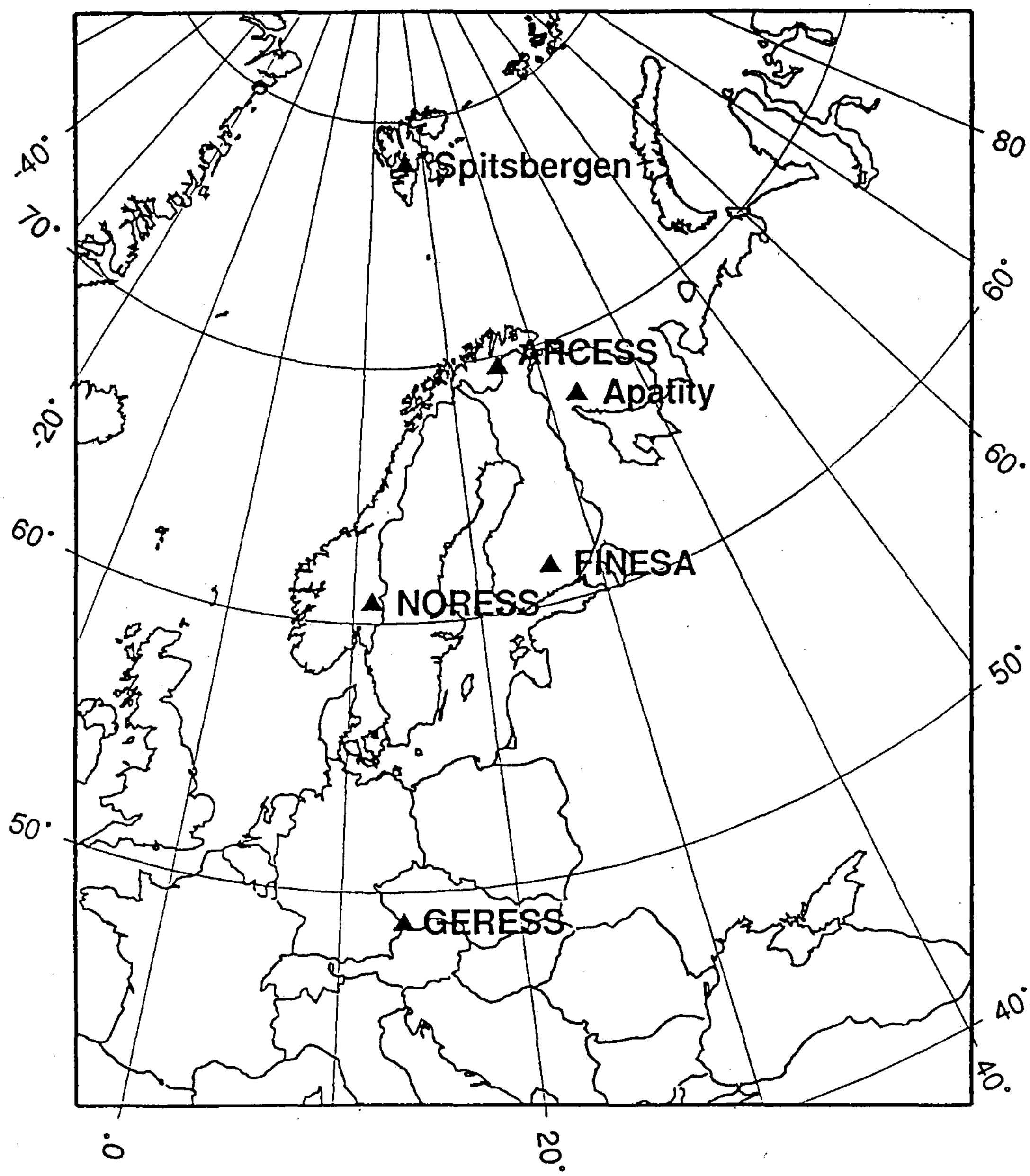

Fig. 7.5.1. Map showing the locations of the six regional arrays currently used by the Intelligent Monitoring System at the NORSAR data processing center.

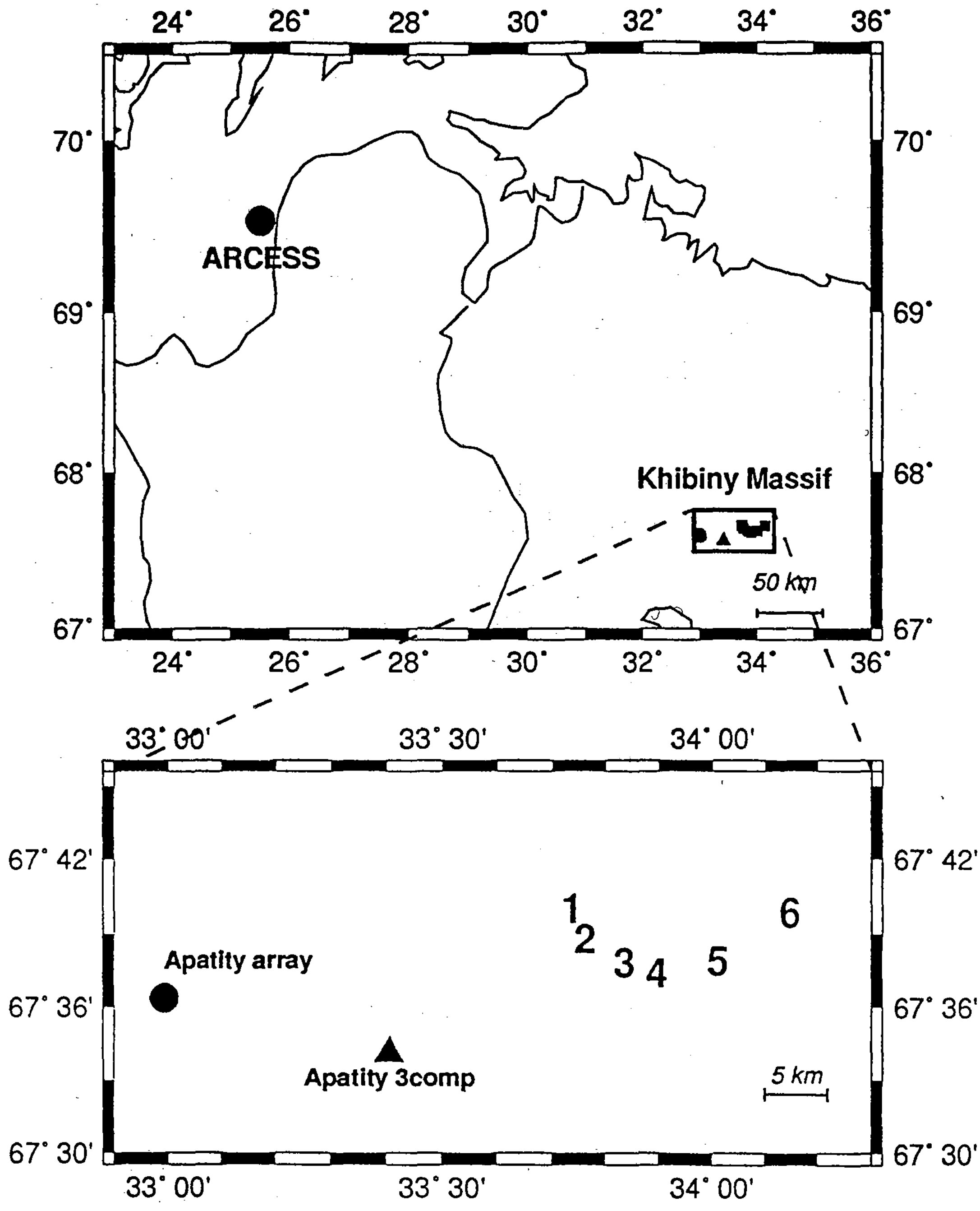

Fig. 7.5.2. In the *upper part*, a large reference area is shown. The location of the ARCESS array is given by a filled circle, and the location of the Khibiny Massif region is shown. The *lower part* shows a detailed picture of the Khibiny Massif region. The locations of the six mining sites are given by large numbers 1-6. The Apatity array (APA0) is shown as a filled circle and the three-component station (APZ9) in the town of Apatity is shown as a large triangle.

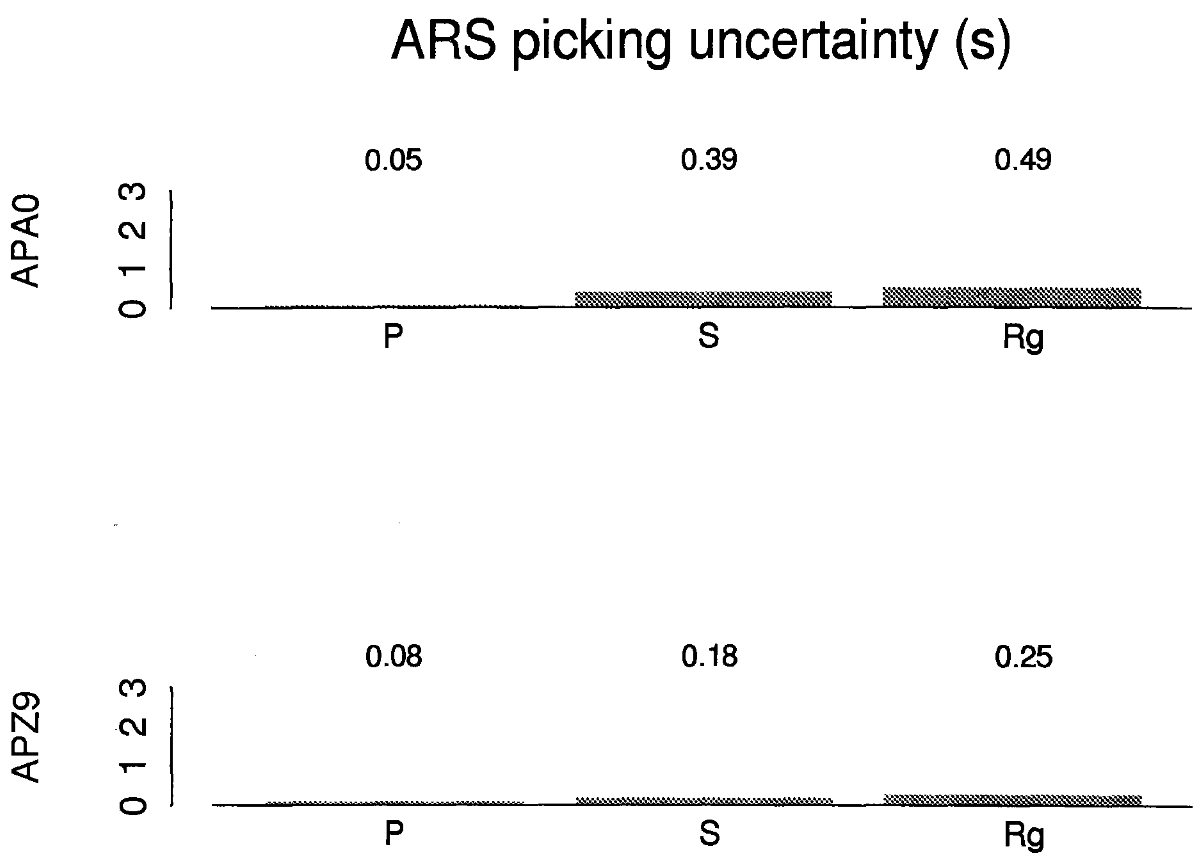

Fig. 7.5.3. Standard deviations of analyst time picks for stations APA0 and APZ9 using the Analyst Review Station (ARS) for the event data base described in the text.

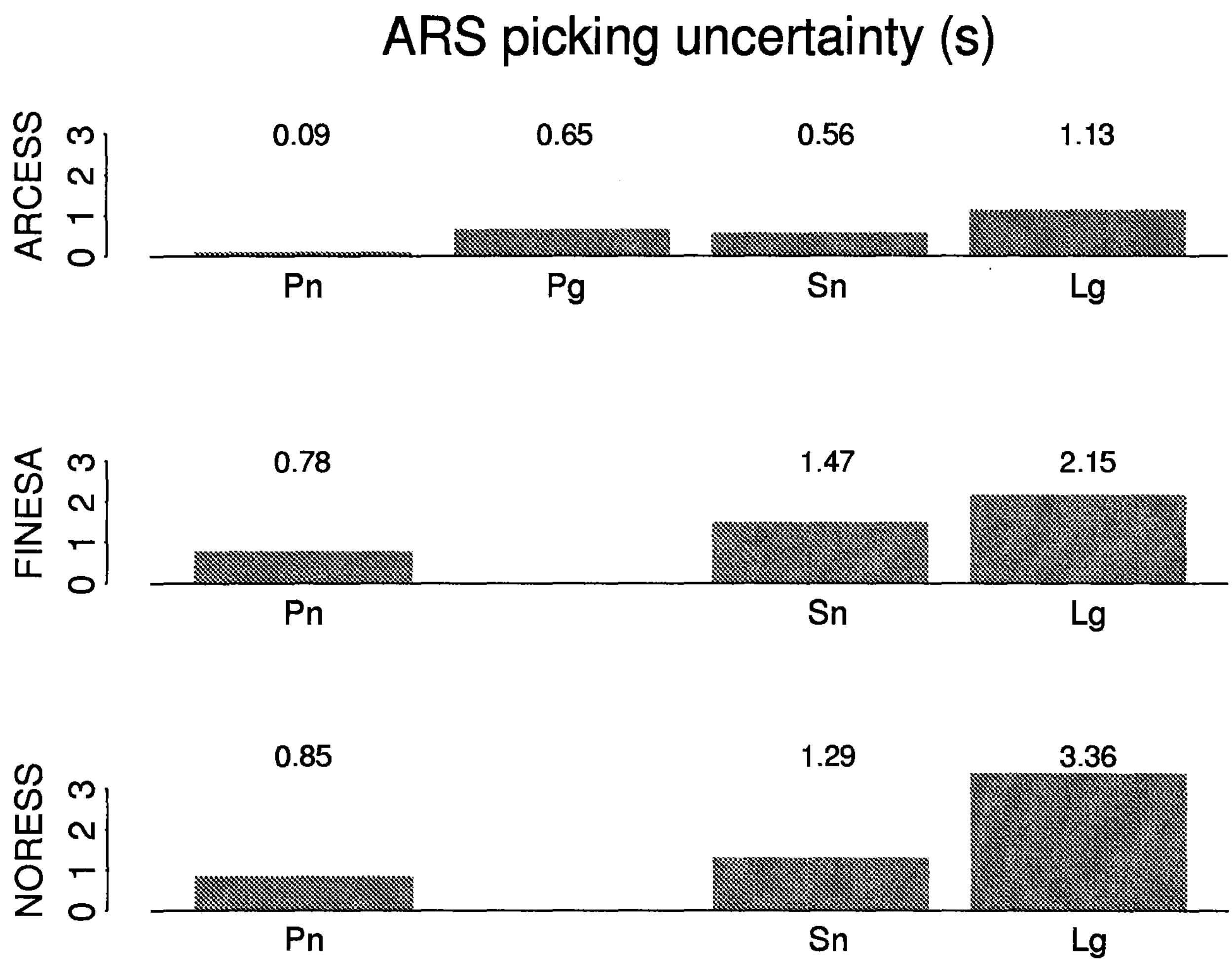

Fig. 7.5.4. Standard deviations of analyst time picks for the arrays ARCESS, FINESA, NORESS using the Analyst Review Station (ARS) for the event data base described in the text.

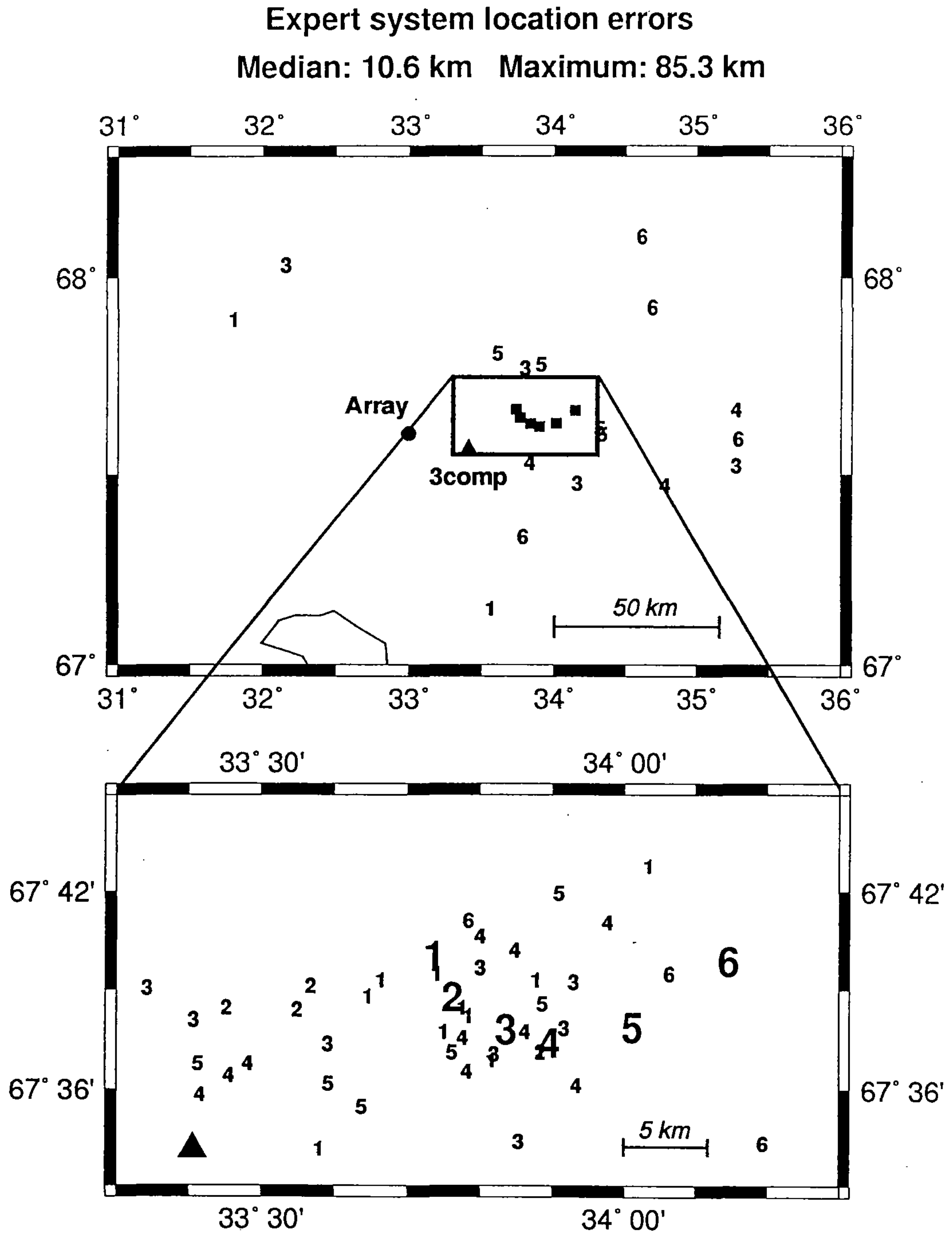

Fig. 7.5.5. Location of the six mining sites in the Khibiny Massif (large numbers 1-6) and the locations of the 58 reference events (small numbers 1-6) as given by the automatic IMS processing. In the *upper part*, a large reference area is shown, with the mines plotted as filled squares. The *lower part* shows a detailed picture for the area near the mines. The small numbers (1-6) associated with each event represent the mine in which the event actually occurred. The Apatity array is shown as a filled circle and the three-component station in the town of Apatity is shown as a filled triangle.

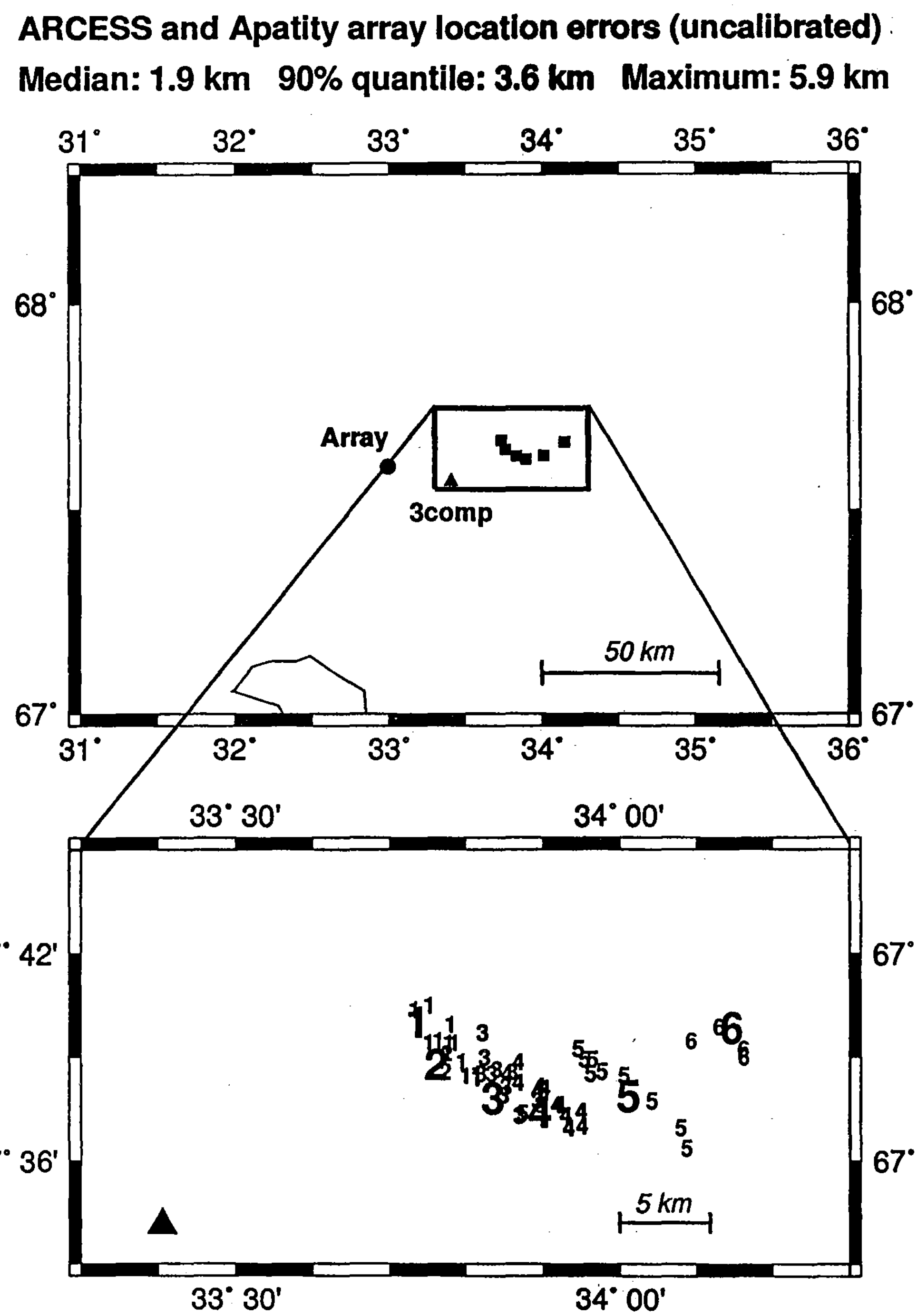

Fig. 7.5.6. Same as Fig. 7.5.5, but showing location results by the automatic post-processing method described by Kværna and Ringdal (1993). Only ARCESS and the Apatity array are used.

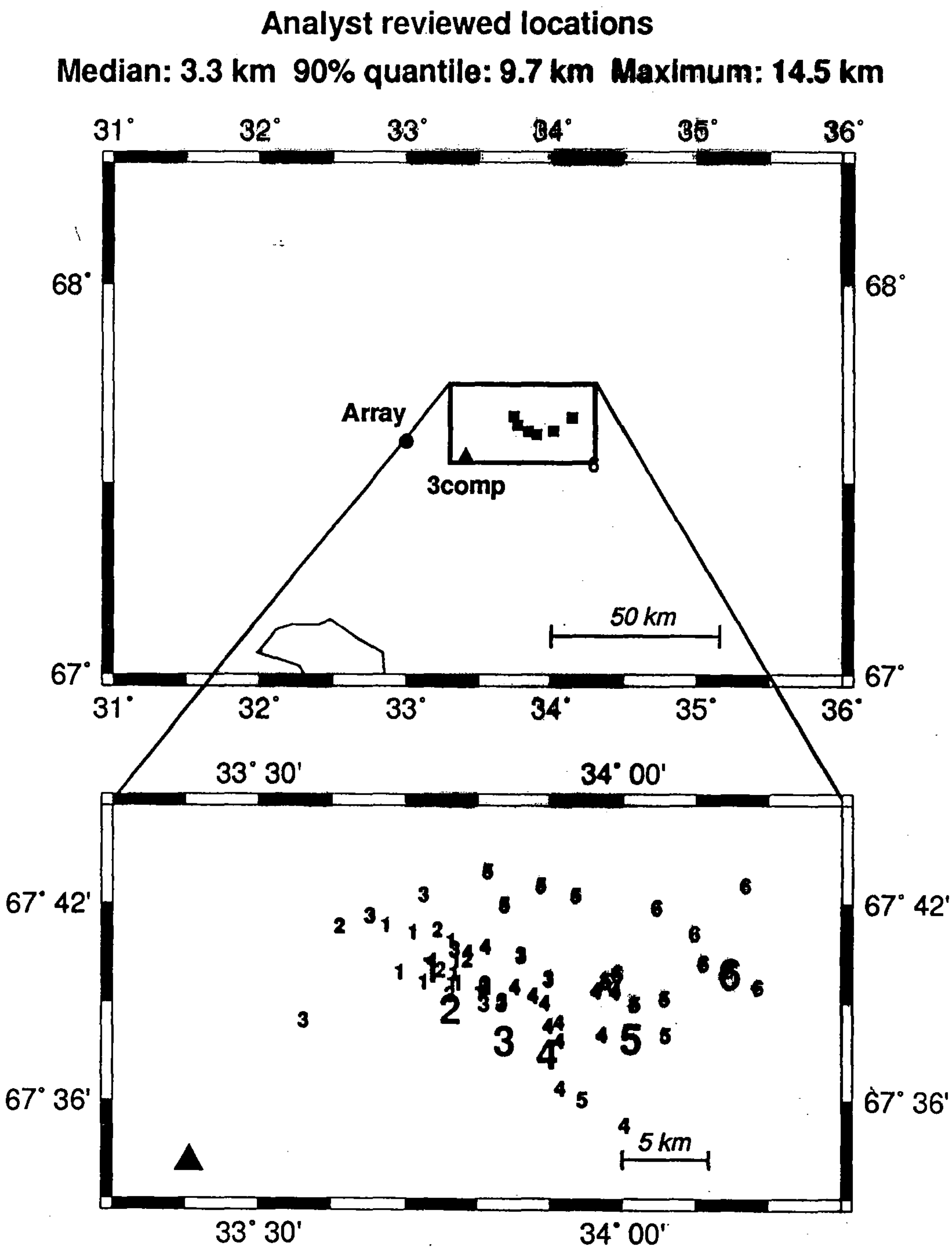

Fig. 7.5.7. Same as Fig. 7.5.5., but showing location results using ARS analysis with four regional arrays (ARCESS, APATITY, NORESS, FINESA).