Work done, and work still needed, to preserve and make usable the analog seismograms of nuclear test explosions conducted in all environments

Paul G. Richards
Lamont-Doherty Earth Observatory of Columbia University

“Securing Legacy Seismic Data to Enable Future Discoveries”
Albuquerque Workshop, September 2019
Work done, and work still needed, to preserve and make usable the analog seismograms of nuclear test explosions conducted in all environments

Paul G. Richards
Lamont-Doherty Earth Observatory of Columbia University

“Securing Legacy Seismic Data to Enable Future Discoveries”
Albuquerque Workshop, September 2019
Work done, and work still needed, to preserve and make usable the analog seismograms of nuclear test explosions conducted in all environments

Paul G. Richards
Lamont-Doherty Earth Observatory of Columbia University

“Securing Legacy Seismic Data to Enable Future Discoveries”
Albuquerque Workshop, September 2019
Work done, and work still needed, to preserve and make usable the analog seismograms of nuclear test explosions conducted in all environments

Paul G. Richards
Lamont-Doherty Earth Observatory of Columbia University

“Securing Legacy Seismic Data to Enable Future Discoveries”
Albuquerque Workshop, September 2019
Work done, and work still needed, to preserve and make usable the analog seismograms of nuclear test explosions conducted in all environments

Paul G. Richards
Lamont-Doherty Earth Observatory of Columbia University

“Securing Legacy Seismic Data to Enable Future Discoveries”
Albuquerque Workshop, September 2019
# Nuclear Tests per decade, for different countries

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>6</td>
<td>188</td>
<td>426</td>
<td>234</td>
<td>155</td>
<td>21</td>
<td>0</td>
<td>0</td>
<td>1030</td>
</tr>
<tr>
<td>USSR</td>
<td>1</td>
<td>82</td>
<td>232</td>
<td>227</td>
<td>172</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>715</td>
</tr>
<tr>
<td>UK</td>
<td>21</td>
<td>5</td>
<td>5</td>
<td>11</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>45</td>
</tr>
<tr>
<td>France</td>
<td>31</td>
<td>69</td>
<td>92</td>
<td>18</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>210</td>
</tr>
<tr>
<td>China</td>
<td>10</td>
<td>16</td>
<td>8</td>
<td>11</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>45</td>
</tr>
<tr>
<td>India</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Pakistan</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>DPRK</td>
<td></td>
<td>2</td>
<td>4</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Numbers in red: these explosions took place in the era of analog recording
almost all nuclear testing in the atmosphere took place in the analog era

Numbers in green: these explosions took place in the era of digital recording

To 4/25/2019
A couple of examples:

the first NE, TRINITY
(1945 Jul 16, 20–22 Kt)

the biggest NE, BIG IVAN
(1961 Oct 30, ~58 Mt)
A couple of examples:

the first NE, TRINITY
(1945 Jul 16, 20–22 Kt)

the biggest NE, BIG IVAN
(1961 Oct 30, ~58 Mt)

both of them, of course, in the atmosphere
The "gadget" is partially assembled. Norris Bradbury, shown here, became the director of Los Alamos after Robert Oppenheimer.
Oppenheimer (aged 41) and Gen. Leslie Groves (aged 49) inspecting the remains of the Trinity test tower, 9 September 1945
INTERPRETATION OF RECORDS OBTAINED FROM THE NEW MEXICO ATOMIC BOMB TEST, JULY 16, 1945

By B. Gutenberg

Records obtained at the following stations were available for interpretation of ground and air waves produced by the New Mexico atomic bomb test:

<table>
<thead>
<tr>
<th>Station</th>
<th>Distance</th>
<th>Courtesy of</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tucson</td>
<td>437 km</td>
<td>U. S. Coast and Geodetic Survey</td>
</tr>
<tr>
<td>Pierce Ferry</td>
<td>740 km</td>
<td>Dr. Carder, Lake Mead Seismological Stations, Bureau of Reclamation, National Park Survey, and U. S. Coast and Geodetic Survey</td>
</tr>
<tr>
<td>Overton</td>
<td>793 km</td>
<td></td>
</tr>
<tr>
<td>Boulder City</td>
<td>806 km</td>
<td></td>
</tr>
<tr>
<td>Palomar</td>
<td>965 km</td>
<td>Stations of the California Institute of Technology</td>
</tr>
<tr>
<td>Riverside</td>
<td>1010 km</td>
<td></td>
</tr>
<tr>
<td>Mt. Wilson</td>
<td>1072 km</td>
<td></td>
</tr>
<tr>
<td>Pasadena</td>
<td>1083 km</td>
<td></td>
</tr>
<tr>
<td>Haiwee</td>
<td>1085 km</td>
<td></td>
</tr>
<tr>
<td>Tenemaha</td>
<td>1136 km</td>
<td></td>
</tr>
</tbody>
</table>

Unfortunately, the time of the explosion is known only within about ± 15 seconds.

Plotting of all data revealed that the first longitudinal wave through the ground (Pn) was recorded only at Tucson, Palomar, and Riverside. From the times of arrival, given below, the apparent velocity of this wave was found as follows:

Riverside-Tucson .................... 7.99 km/sec.
Palomar-Tucson ...................... 8.04 km/sec.

These results agree, within the limits of error, with the value of 8.06 km/sec. found for southern California earthquakes. Thus it is possible to calculate the origin time, using for each of the three stations the travel times for zero depth (Gutenberg-Richter, 1939, p. 97).

<table>
<thead>
<tr>
<th>Station</th>
<th>Distance</th>
<th>Observed time</th>
<th>Travel time from tables</th>
<th>Origin time (GCT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tucson</td>
<td>437 km</td>
<td>11:30:26:3</td>
<td>1:04</td>
<td>11:29:22</td>
</tr>
<tr>
<td>Palomar</td>
<td>965 km</td>
<td>11:31:32</td>
<td>2:11</td>
<td>11:29:21</td>
</tr>
<tr>
<td>Riverside</td>
<td>1010 km</td>
<td>11:31:38</td>
<td>2:16</td>
<td>11:29:22</td>
</tr>
</tbody>
</table>

The P wave through the "granitic" layer was recorded at Tucson at 11:30:38. Supposing that the velocity of this wave was about the same as in California (5.58 km/sec.), its travel time would have been 78.3 seconds. This would give an origin time of 11:29:20. The agreement is very good, considering the fact that the travel time of Pn depends on the depth of the Mohorovičić layer. An origin time of 11:29:21 was used in the following calculations. It is probably correct within two seconds and is within the interval considered as probable from the direct observations.
Fig. 8. Speed of sound versus altitude at 45° N (from U.S. Standard Atmosphere Supplements, 1966) as a function of temperature alone, for January (dotted line), Autumn-spring (solid line), and summer (dashed line).
Fig. 19. Acoustic ray propagation from a point source to the east in summer, at 12:00. Vertical angles of incidence every 3 degrees between 52 and 85 degrees.
the regional seismic waves again (they are the most challenging to digitize)
an infrasound signal about 21 minutes after Pn
a second infrasound signal, about 23 minutes after Pn (it generates even bigger ground motion than the direct seismic waves)
Press-Ewing three-component, long-period seismographs (red triangles) deployed during 1954-1958

Many were deployed during the IGY in 1957-1958 and were still operating in the early 1960s (before WWSSN)
In Memorium

Paul W. Pomeroy
1931 - 2019
MTJ    Z 1961-10-30

shows Rayleigh waves and A1 (~ 5 hours)

\[ \Delta = 55^\circ \]
MTJ   Z 1961-10-31

shows A2 (~ 28 hours)

\[ \Delta = 305^\circ \]
MTJ    N 1961-10-30

A1 induces tilt

shows Rayleigh waves and A1 (~ 5 hours)

$\Delta = 55^\circ$
If the horizontal records of A1 are rotated using a back-azimuth of 327° (the approximate azimuth to the test site), the transverse component effectively disappears, as plotted below. The signals are filtered from 100 to 1000 s.
Tsar Bomba

Spectrograms for A1 and A2 arrivals on the Z component are plotted below. In order for a consistent color scale to be used across both spectrograms, the amplitude of the recorded A2 data has been scaled by a factor of 5 (without scaling, the A2 spectrogram is invisible).
Raising issues both Large and small (some are very small)

Paper lasted very well (Will bits?)

We need to document:
earthquake cycles;
(centuries)
and a unique human activity
(nuclear testing)
Issues:
what assets are available?
what are the priorities
(what to save... merits of triage)?
the relative importance of
scanning and digitizing?
who could/should do the work (cost)?
(experiences elsewhere —
Europe, China, Iceland...)
how best to distribute data products?