t_{ij} is the measured arrival time of the i th seismometer in the j th array relative to an arbitrary baseline, S_{ij} is a correction to the arrival time at the seismometer caused by local geology, C_j is an arbitrary constant, (R_{ij}, θ_{ij}) are polar coordinates of the seismometer relative to the array centre, Δ_j is the epicentral distance to the approximate epicentre, A_j is the reciprocal of the phase velocity calculated for the epicentral distance Δ_j , α_j is the azimuth of the approximate epicentre, β_j the azimuth of the array from the epicentre. All these quantities, except S_{ij} can be calculated from the array, approximate epicentre and measured arrival times. S_{ij} has to be estimated independently using methods similar to that of Douglas and Corbishley². δC_j , δx and δy , the corrections to C_j , latitude and longitude of the epicentre, have to be calculated. If a phase velocity curve is not used, the equation of condition is

$$\delta t_{ij} = \delta C_j + (\Delta_j^{-1} A_j R_{ij} \sin(\theta_{ij} - \alpha_j) \cos \beta_j) \delta x - (\Delta_j^{-1} A_j R_{ij} \sin(\theta_{ij} - \alpha_j) \sin \beta_j) \delta y - R_{ij} \cos(\theta_{ij} - \alpha_j) \delta A_j$$

where δA_j is the correction to A_j which is considered as another unknown. Thus this method depends purely on the azimuth determining properties of the arrays. Using either equation of condition, corrections in both cases can be estimated by least squares then applied to the approximate epicentre, and the process repeated until the corrections become small.

To test both methods, events from Kazakh (central Russia) recorded by the four arrays, GBA (India), WRA (Australia), YKA (Canada) and EKA (Scotland) were considered. Epicentres computed using travel times indicate that these events all occurred in an area about 0.25 degree square⁶. Relative arrival times were measured as described by Douglas and Corbishley²: the trace of one seismometer is used as master to fit the other traces on the same array.

Convergence to the best (least squares) estimate of the epicentres was rapid when the phase velocity curve was used, but for the "azimuth only" method the estimates tend to oscillate initially before converging. The mean position of the relocated epicentres is about 400 km north of the "true" positions using both methods. Average deviations from this mean position were 150 km and 200 km respectively, results in agreement with the confidence limits being given by the least squares analysis. Inappropriate corrections S_{ij} are the cause of the mean error of 400 km; a trend in S_{ij} across an array would cause an error in location but would not be manifest in the confidence limits. These corrections (S_{ij}) are known to vary with azimuth to the event but have not yet been completely evaluated for the Kazakh events.

Relocation of the nuclear explosion Longshot in the Aleutians, which is at azimuths appropriate to corrections available, was in error by 60 km and 150 km respectively for the two methods.

Clearly these results are less accurate than epicentres determined by conventional means, but several points should be considered. Only four arrays were available, a situation which will improve in the future. Arrays are being used to improve phase velocity curves²; the results given here were obtained using differentiated Jeffreys-Bullen travel times. The method using azimuths alone has interesting possibilities. Location of near events is free from troubles associated with errors in the travel time curve, and at the same time the reduced distances involved will give a proportional increase in accuracy³⁻⁵. Also, because azimuths alone are used, the method can be applied in fields outside seismology, such as the acoustic arrays described by Grover⁷. More than one array is essential in this case because the velocity of acoustic waves is not a known function of distance.

As mentioned at the beginning of this communication, the location process can be automated. Weichert *et al.*¹

described how this can be done for one array by combining the seismometer outputs electronically and making an automatic search for events. This is possible because only relative and not absolute arrival times are required. Extension to several arrays, on a world wide or local basis, would lead to the possibility of continuous monitoring of epicentres.

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Curvature of Island Arcs

A FLEXIBLE but inextensible thin spherical shell may be bent inwards through an angle θ on and only on a circle whose radius of curvature (expressed in angular measure on the sphere) is $\frac{1}{2}\theta$. This is easily proved with a geometrical construction involving two equal intersecting spheres, and can be demonstrated on a punctured ping-pong ball. This affords a simple explanation of the shape of island arcs and related arcuate geographical structures. The interpretation¹ of island arcs, or rather the ocean trenches which lie outside them, as the places where oceanic crust, spreading from mid-oceanic ridges, bends downwards to return into the mantle is now widely accepted (compare various contributions to ref. 2). The dip of this return path is revealed by the location of earthquake foci on a surface which slopes downwards to a depth of 700 km at 45° (ref. 3) (if one discards an analysis in terms of two successive slopes, one shallower and the other steeper, which the uncertainty of focal depth determination does not justify). The Kamchatka-Kurile arc, the Alaska Peninsula-Aleutian arc and the Sumatra-Java arc all have radii of about 20°, or about 22° measured out to their associated trenches, in consonance with dips of 45°. The arcuate curvatures of the Himalaya and the Andes, though rather more difficult to specify precisely, are of about the same magnitude.

The dip presumably takes the value 45° because of maximum shear stress. Customary doctrine indicates that the preferred plane for compressive faulting should be one of shallower dip, with smaller normal stress and therefore smaller friction. The argument will not apply if movement only occurs as a result of fluid accumulation⁴.

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