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REPORT ON PHASE BLOCKAGE PHENOMENOLOGY SESSION, SSA 91ST ANNUAL MEETING, 2 APRIL 1996, ST. LOUIS, MISSOURI

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This report details the results of a special session on regional phase blockage which was held during the Seismological Society of America's 91st Annual Meeting in St. Louis, Missouri on April 2, 1996. The session consisted of seven orally presented papers by members of the seismic monitoring research community and a follow-up meeting that was intended to be a discussion session about the scientific problem of phase blockage. The report contains the abstracts from the talks, background on regional phase blockage, some results from the papers presented at the session, and some conclusions and recommendations for future research by the authors.

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PREFACE

This project was conducted under the auspices of the *Air Force Technical Applications Center* and the *Earth Sciences Division of the Air Force Phillips Laboratory.* The views and conclusions contained in this report are those of the authors and should not be interpreted as representing the official policies, either expressed or implied, of the U.S. Air Force or the U.S. Government.

SUMMARY

A special session on *Regional Phase Blockage Phenomenology* was held on April 2, 1996, at St. Louis, Missouri, during the *SSA 91st Annual meeting.* The session was a result of several discussions between Phillips Laboratory (PL/GPE), AFOSR, and DOE's national laboratories after the *17th Seismic Research Symposium.* The motivation was to gather Comprehensive Test Ban Treaty (CTBT) researchers to review the status and current direction of research on blockage-related topics, and if appropriate, make some suggestions on follow-up topics. The morning session of oral presentations, presided over by Dr. Delaine Reiter (PL/GPE) and Rong-Song Jih (PL/GPE), was followed by a wrap-up discussion that evening convened by Dr. Stanley Dickinson (AFOSR) and Dr. Delaine Reiter (PL/GPE). This report provides some background on regional phase blockage and summarizes the results from the morning session and the issues that were addressed at the discussion session. The seven abstracts presented at the morning session are included in an Appendix to this report with titles of the talks listed below:

1. Baumgardt, L_g *propagation-path barriers in the Eurasian continental craton -- possible shallow crust explanations.*
2. Priestley, Schultz, and Patton, *Anomalous surface wave propagation across the south Caspian basin and the blockage of regional seismic phases.*
3. Jih, McLaughlin, Dainty, and Harkrider, *Numerical modeling of* R_g *blockage and comparison of* R_g*-to-*L_g *conversion mechanisms due to scattering and incomplete dissipation.*
4. Xie, P_n *amplitude variation along the northern foot of the Tienshan mountains.*
5. Anderson and Cormier, *Regional variations in* L_g *observed and synthesized at the CNET and KNET arrays.*
6. McNamara, Walter, Schultz, and Goldstein, *Regional phase propagation in northern Africa and the Mediterranean.*
7. Sweeney, *Interpretation of crustal phase characteristics in Iran and the surrounding region determined from ILPA data.*

These papers will be referred to by their title numbers throughout the remainder of this report.

BACKGROUND INFORMATION

The most prominent regional phase generated by shallow events is the L_g phase identified by Press and Ewing (1952). The L_g phase has received considerable attention in recent years because of its potential use in yield estimation (*e.g.*, Nuttli, 1986) and discriminating between earthquakes and explosions at regional distances (*e.g.*, Blandford, 1981; Pomeroy *et al.*, 1982). Based on empirical observations, L_g has been recognized as a stable relative-yield indicator (Patton, 1988; Hansen *et al.*, 1990). However, it is also recognized that L_g, like R_g, is sensitive to changes in structure along its path, which can have deleterious effects on any role as a discriminant (*cf.* Lynnes and Baumstark, 1991) or magnitude measure (*cf.* Jih and Lynnes, 1993), unless the propagation effects are accurately accounted for. Numerous studies have used the sensitivity of L_g to structural effects to map regions of anomalous propagation and try to associate them with crustal structure. Bias in L_g-based magnitude measurements were reported by Gregersen (1984) in Greenland. Very low L_g/S_n amplitude ratios have been observed after crossing the Tibetan plateau (Ruzaikin *et al.*, 1977), the North Sea grabens (Gregersen, 1984; Kennett *et al.*, 1985), the Caspian Sea or the Black Sea (Levshin and Berteussen, 1979; Kadinsky-Cade *et al.*, 1981). Chinn *et al.* (1980) (and Lynnes and Baumstark, 1991) observed that the efficiency of the L_g propagation is better for paths parallel to the structural trend than for paths in the perpendicular direction. Earlier studies (Press and Ewing, 1952; starkr and Ewing, 1957; Savarensky and Valdner, 1960) have established that L_g does not propagate through crust overlain by water deeper than 2 km. On the other hand, propagation across a marginal sea of continental shelf does not completely quench L_g, but can reduce its amplitude. Baumgardt (1991) compared the crustal cross-sections for L_g propagation, and found that the L_g blockage correlates with thick sediment very well. Basically, his observation was that paths that do not cross basins or for which sediments do not vary by greater than 3 km exhibit little or no L_g blockage and scattering. Baumgardt (1991) also identified paths for which the surface elevations and crustal thickness change substantially, and yet L_g propagates efficiently. Thus his observations suggest that the near-surface sediment-thickness variations seem to correlate more strongly with L_g blockage than do the crustal-thickness variations. Zhang and Lay (1994) used surface topography as a manifestation of the varying crustal structures. They found a strong correlation between S_n/L_g ratios for Eurasian explosions and roughness or mean altitude of the topography along the path, based on a meager data set.

Despite the long-time interest, many fundamental questions about the excitation and propagation of L_g waves phases remain to be answered. Numerical modeling of the L_g waves (and other regional phases) would complement the empirical studies by providing more accurate interpretations and better insight of the underlying physics. Theoretical studies of L_g propagation across continental margins have been conducted by Kennett (1986), Maupin (1989), Regan and Harkrider (1989), Cao and Muirhead

(1993), and Gibson and Campillo (1994), using different techniques. A simple geometrical ray theory can be used to predict the kinematic property in a qualitative manner, as Kennett (1986) has illustrated, but would fail to explain the dynamic properties for complex media. Kennett and his associates used a modal summation to investigate L_g propagation in stratified and weakly heterogeneous media. Mitchell and Hwang (1987) computed multi-mode synthetics for 1-D models with various thicknesses of low-Q sediments. Regan and Harkrider (1989) used a hybrid of propagator matrix and finite-element [FE] methods to model the *SH*-L_g-wave propagation. Cao and Muirhead (1993) applied a 2-dimensional P-SV finite-difference method to explore L_g blockage and argue that a water column over the crust is an important factor in blocking L_g propagation. Gibson and Campillo (1994) applied both the dynamic ray tracing and the boundary-integral equation methods to model L_g blockage in the west Pyrenees Range, near the French-Spanish border. They suggest that the unmodeled scattering by small-scale features within the lower crust is the reason for the observed blockage. Jih (1995, 1996b) implemented a pure L_g wave packet for Linear Finite Difference (LFD) calculations. This strategy works particularly well for models with additional levels of complexity due to free-surface topographic irregularities and anelastic attenuation. Jih (1996a) (and [3]) pointed out that a shallow, strong attenuative layer near the surface could cause R_g-to-higher mode coupling. As a result, some undissipated R_g energy could propagate as crustal S waves like L_g. This is rather surprising and seems to be a special mechanism only affecting R_g. The significance of the LFD modeling research by Jih and his partners at both former Teledyne Geotech and Phillips Laboratory is that their distinct code permits a convenient investigation of the path effect (due to a specific mechansim) on a specific phase.

SIGNIFICANT FINDINGS FROM THE SSA MORNING SESSION

From the seven talks from the morning session, there are several observations worth reporting:

[A] With the exception of one theoretical study [3], all the other talks were based primarily on empirical observations. A few of the empirically-based talks were supplemented with minor modeling efforts. The synthetic techniques used include the LFD method (*e.g.*, [2]), ray-tracing (*e.g.*, [5]), and a hybrid method using LFD and locked mode (*e.g.*, [3]).

Several of the authors' results indicate that shallow, lateral crustal heterogeneity can explain much of the variability in high-frequency L_g and long period surface waves in the continents ([1-3],[6]). At least two of the studies indicate that sedimentary basins combined with thinned crust are especially efficient at attenuating L_g; such structures are easily modeled using 2D approaches. One question that then arises is how geological structures that are not sedimentary basins can block L_g ([1] used the example of the Tsangpo/Indus suture zone), and how these effects could be modeled.

The principal conclusion reached by the authors of [5] is that strong gradients in Moho topography combined with increasing length of path across such topography correlates well with decreased L_g efficiency. This contrasts with the results from papers [1], [2] and [4], which indicate that Moho topography is a secondary effect compared to upper crustal heterogeneity. One possible explanation for this discrepancy is that the modeling technique (ray-tracing) may bias the author's conclusions towards topography as a predominant cause of surface wave blockage.

[B] While the L_g phase remained the theme of several talks, several PIs have investigated other regional phases such as R_g and P_n. This kind of study is important because blockage of one phase in the crustal and/or mantle waveguide is often associated with coupling or conversion to another phase.

For instance, in [3] Jih *et al.* numerically modeled pure R_g using 2D linear finite difference (LFD) and compared a number of physical mechanisms and their effects on waveforms. These mechanisms included rough topography and random heterogeneity. They also looked at $R_g \rightarrow L_g$ conversion in the presence of shallow, highly attenuative layers. The relative effectiveness to block R_g using all three mechanisms was compared. This study provided a clear picture of the expected effect on waveforms using three important and viable physical mechanisms.

In [4] Xie used P_n amplitude variation as an indicator of crustal heterogeneity. He found that P_n variation is much more unpredictable than other phases. It is also more difficult to tell what is causing the variability; it could be a number of mechanisms such as 3-D heterogeneity, caustics at the surface and Moho, or near-surface structural variation. Further study is necessary to quantify which, if any, of these mechanisms can explain the variability in P_n.

[C] Many of the presented talks utilized a variety of seismic data sources ranging from recently recovered historical ILPA data ([7]) to data recorded at the newly deployed KNET and CNET ([4,5]). The significance of utilizing these new data sources in regions of great CTBT concern is that it demonstrates the reliability and usefulness of the new networks. It is hoped that further studies using data from regions of CTBT interest will further complete maps of regional phase blockages and explain some of the mechanisms which cause blockages.

CONCLUSIONS

L_g phase blockage on the continents appears to be closely tied to upper crustal structure. The modeling and empirical studies show that L_g waves traversing regions with thick sedimentary basins or other strong lateral variations are effectively blocked. A second and, to our minds, less important cause of phase blockage is that of topography, both surface and Moho. Other phases, such as P_n, are also sensitive to upper crustal structure and Moho topography, but they are less well understood.

If the empirical studies are done correctly (that is, they separate out the effects on blockage of source mechanism and other forms of attenuation from that due to pure path blockage from topographic or structural variations), they can provide a valuable database or "map" of blockage in regions of CTBT interest. An empirical approach serves the research goal well to the extent of confirming the phase blockage. However, once the blockage is observed in a new region (or, in some cases, a well-studied region), perhaps the effort should be directed towards improving the fundamental understanding of (a) the physical mechanism as well as (b) the possible implication for event discrimination. These two branches generally reflect the difference between 6.1 and 6.2 projects. Obviously from a CTBT-monitoring point of view, it is never enough to "re-confirm" a phase blockage phenomenon. At some point, the PI should move forward to either (a) try to solve the scientific puzzle or (b) find some correction procedure to account for the phase blockage. Either one will improve our capability in monitoring a CTBT in the regional regime. Very often, though, these two goals are intertwined and difficult to separate.

Modeling studies done in conjunction with empirical observations (such as papers [2] and [6]) can reveal the causes of blockage, as long as they use an appropriate modeling technique that can simulate the full wavefield. Studies like [3] are important to understanding the physical mechanisms of a particular type of propagation and blockage, in this case R_g.

RECOMMENDATIONS

In our opinion the problem of phase blockage divides fairly naturally into 6.1 (basic) and 6.2/6.3 (applied) type research programs. A basic research program should be focused on adding to our further understanding of the physical mechanisms of L_g, Sn and P_g/P_n blockage. This includes work on establishing the physical basis for discriminants in terms of source mechanism and regional phase excitation. Without a firm foothold in source theory, questions about transportability will continue to go unanswered, particularly in regions where few if any nuclear explosions have been tested before.

Establishing the physical basis can be very difficult because there are usually several competing mechanisms, which can often be coupled and poorly understood. A particularly challenging puzzle concerns the physical basis for the P-to-S ratio and the spectral ratio discriminants. The focus here is primarily on the generation of explosion L_g waves and the role of spall versus the role of R_g-to-S conversions.

R_g-to-S(L_g) conversion in the source region is a propagation effect involving a disrupted waveguide or heterogeneity in the medium. On the other hand, explosion L_g may be generated predominantly by intrinsic source mechanisms, especially at high frequencies. (See McLaughlin et al., 1988; Patton and Taylor, 1995; and Jih's talk at this SSA for some aspects of this issue.) This is a typical example of uncertainties in our physical understanding of regional phase excitation due to the (current) inseparability of source and path effects.

A basic research program should also include work on a predictive capability that can model fully 3-D elastic propagation efficiently in the high-frequency (1-10 Hz) regime out to regional distances (1000 km and further). The study of the blockage of other regional phases besides L_g is also important, especially as it relates to location and discrimination.

We think an applied program should complement the basic research studies with projects aimed at empirically mapping blockage in regions of CTBT interest. This could include projects using both historical (such as the ILPA dataset) and current data sets. This type of work will be important in completing the calibration of different regions using regional seismic data. In addition, the applied program is the appropriate place to conduct benchmark tests of different numerical modeling techniques.

Both the basic and applied research programs could involve field studies; however, the design and purpose of these experiments should be very carefully planned. Unless the proposed experiment is carefully designed to solve some specific scientific puzzle, it might end up to be a nonproductive training experiment. During 1995 DoE conducted five field experiments (Stump *et al.*, 1996; DoE, 1996), and the Air Force (PL and AFOSR) also funded at least two experiments. In our opinion it may be preferable to digest the data from these experiments somewhat before more field experiments are conducted.

Possible basic and applied types of field experiments:

1. A 6.1 experiment should be designed to solve some fundamental scientific puzzle or issue that is relevant to Air Force's treaty monitoring need. Currently the most important outstanding question is the relationship between near-source media and the mechanics of sources to radiated seismic signals. This type of question cannot be answered by refraction surveys, simply deploying more sensors or making more field trips.

A good example of a relevant 6.1 experiment is the DoE field program led by Brian Stump's group at Los Alamos National Laboratory. During 1995, Stump *et al.* (1996) conducted a series of field experiments with very specific goals attached to each experiment. For instance, his "Source Geometry" experiment was designed to compare spherical (typical of tamped underground nuclear explosion) and cylindrical explosions (typical of mining explosions) and to develop monitoring techniques for both types. In the "Black Thunder" experiment, Stump's research goal was to document the effect of blasting practice on observable seismic signals (see also DoE, 1996).

Although a basic research program like AFOSR's is the ideal vehicle to fund experiments of the 6.1 type, such experiments (like Stump's) are prohibitively expensive. As a result, only very few PIs can be funded to conduct this type of research. What the 6.1 community should do is perhaps to team with Stump and analyze his data jointly, rather than trying to duplicate his experiments at the expense of other fundamental research. Perhaps the funding agencies should make a major field experiment every two or three years a central element of all of the agencies' programs. This would take major coordination efforts among AFTAC, DARPA, DoE, DNA, Phillips Laboratory, and AFOSR, plus potential participants from foreign countries, but the experiment could serve to develop some commonality among the investigators.

2. A 6.2/6.3 type of field program should include reconnaissance surveys for regions of monitoring concern that have not been explored well before. Agencies that manage 6.2/6.3 programs should fund studies that attempt to gather useful data to form an usable archive. For this type of experiment, the selection of site is critical, and the basic research program should therefore not be obligated to fund this type of experiment. In fact, if a PI is interested in "calibrating" a region of high monitoring concern through a series of field experiments, the relevant agencies who would use the results had better be consulted in advance.

The worst scenario is for a PI to be funded under 6.1 to conduct an experiment with no scientific goal in mind or funded under 6.2 to conduct experiments in an area of no 6.2 relevance at all. Such experiments are neither a 6.1 nor 6.2 project - they serve at best as a training trip for the technicians. Such experiments bear no relevance to the Air Force's mission and should not be funded by the 6.1 or 6.2 programs, especially when the budgets of these programs are already extremely tight.

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APPENDIX: ABSTRACTS PRESENTED AT PHASE BLOCKAGE SESSION, SSA 91ST MEETING

L_g Propagation-Path Barriers in the Eurasian Continental **Craton -- Possible Shallow Crust Explanations**

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Investigations of regional seismic phase propagation in Eurasia, including Scandinavia, Europe, Russia, and China, have revealed numerous instances of anomalous attenuation, or "blockage", of the regional shear phase, L_g. Because many regional seismic discriminants used to monitor comprehensive test ban treaties rely on L_g amplitude and spectral measurements, it is important to understand the origin of sudden L_g attenuation.

L_g barriers in the Eurasian continental cratons are related to laterally heterogeneous shallow crustal structure. Such heterogeneities appear to distort the crustal waveguide for L_g and thus produce a sudden blockage of L_g propagation through the anomalous region. In the continents, L_g blockages have been observed for deep sedimentary basins which act as L_g "sinks", *i.e.*, they trap L_g waves which pass through due to strong impedance contrasts between the low-velocity sediments in the basins and granitic-velocity rocks outside of the basins. Crustal thickness variations (e.g., crustal pinchouts) do not seem to be implicated in these blockages since the crustal thickness does not vary by more than 10 km in these regions, even under mountainous regions like the Urals. Examples of such regions include the Barents Sea, Pechora, Caspian Basins, and sedimentary basins around the Urals in Russia.

In China, strong blockage of high-frequency (>1 Hz) L_g has been observed for propagation paths crossing southern Tibet, although L_g does appear to propagate efficiently across northern Tibet. Moreover, low-frequency (<1 Hz) L_g does not seem to be blocked in any of these regions. L_g blockage in Tibet has usually been attributed to anomalous crustal thickness and high anelastic attenuation. Although Tibet is ringed by sedimentary basins, such as the Tarim Basin in the north, the sediment depths are shallow and do not seem to strongly block L_g in the north. However, since many of the blocked L_g paths in southern Tibet cross the Tsangpo/Indus suture zone, a region of anomalous geological structure, it is possible that this suture zone may be a thin boundary in southern Tibet that blocks high-frequency but not low-frequency L_g waves.

These results suggest that lateral heterogeneity in shallow crustal structure may be a major cause of high-frequency L_g blockage in the continents. More observations from new stations now appearing in Eurasia will be needed to more thoroughly map out regions of anomalous L_g blockage in order to explain their origin and to properly calibrate regional discriminants which utilize measurements of the L_g phase.

Anomalous Surface Wave Propagation across the South Caspian Basin and the Blockage of regional Seismic Phases

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The crust and upper mantle structure of the south Caspian Basin is enigmatic. Early Soviet studies show that the crust of the basin consists of two layers: a thick sedimentary section (15-25 km) with low P-wave velocity (3.5-4.0 km/s) overlying a 12-18 km thick basaltic lower crust. The study of Kadinsky-Cade *et al.* (1981) demonstrated that the seismic phase L_g is largely blocked for paths crossing the south Caspian Basin. New seismic data shows that the south Caspian Basin also severely disrupts low frequency (0.017 -0.10 Hz) fundamental mode surface wave trains. The effect is observed for surface waves propagating along both east-to-west and west-to-east great circle paths showing that this is not a site or instrumental effect. We model the response of the surface wave to this low-velocity sediment, deep basin structure and crustal thinning using a hybrid locked-mode/finite-difference approach. We demonstrate that much of the observed surface wave train degradation can be modeled with the 2-D basin structure. Finally we demonstrate how a simple model of the structure in the Caspian region can help identify blockage mechanism.

Numerical Modeling of R_g Blockage and Comparison of R_g-to-L_g Conversion Mechanisms due to Scattering and Incomplete Dissipation

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The presence of a short-period fundamental-mode Rayleigh wave, R_g, is an excellent diagnostic for shallow source depth. However, R_g is susceptible to non-uniformities of the near-surface waveguide, and hence absence of R_g does not imply a deep source. Without a predictive capability, the usage of R_g will be limited to well-calibrated source regions and propagation paths. Study of R_g propagation (scattering, attenuation, *etc.*) would naturally help constrain source depth and thereby help event identification also. In this study, intensive linear finite-difference [LFD] calculations are conducted to explore the physical mechanisms of R_g blockage with emphasis placed on quantification of the scattering effects due to rough topography and random heterogeneity. In addition, a new R_g -to- L_g conversion mechanism due to incomplete dissipation by shallow, strong attenuative layers is presented and the relative effectiveness of all three R_g-related mechanisms are compared. For models embedded with shallow random heterogeneity, the RMS velocity fluctuation correlates very well with the R_g transmission coefficient. For 1 Hz R_g, a 2%–5% variation in the velocity leads to an equivalent spatial Q value of several hundreds or larger, regardless of which of the three commonly used random media is embedded. Rough topography typically results in a Q value ranging from 10 to 100, which is approximately equivalent to a random medium with velocity variation larger than 10%. Incomplete dissipation of R_g waves produces a very simple wave field, with almost all of the undissipated energy propagating laterally towards the forward, and hence postcritical, directions. On the other hand, the scattering by shallow heterogeneity or rough topography generates a rather complicated wave field, with a significant fraction of the scattered energy going steeply downward. In terms of energy partitioning between converted P and S waves, the incomplete dissipation overwhelmingly directs more energy into S (L_g) waves, as compared to the remaining two mechanisms. For whichever of the three R_g-blocking mechanisms is invoked, the S waves converted from R_g always dominate the whole scattered field.

Pn amplitude variation along the northern foot of the Tienshan mountains

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The term "blockage" of regional waveforms has been used to describe drastic amplitude reductions of regional waveforms. This term, however, is typically used in a qualitative and relative sense. For example, blockages of L_g or S_n phases require less amplitude reduction than that of the primary (P) phase since L_g or S_n are preceded by coda of other phases which may have considerable amplitude. In reality, the amplitude of P waves often vary much more drastically than that of the L_g phase, and in a much more unpredictable manner. We present a case in which the Pn phase from Lop Nor explosions undergoes a drastic variation in amplitude (by a factor of 30) across the Kyrghizstan Network (KNET). This network is deployed along the northern foot of the Tienshan mountains and has a relatively small ($\approx$ 100 km) aperture. The amplitude variation primarily occurs at lower ($\approx$ 1 Hz) frequencies, and is accompanied by anomalous polarizations. At station KZA where the largest Pn amplitude is observed, Pn is polarized to N60°W, about 30° away from the great circle. The cause of the amplitude and polarization anomalies are likely to be some deep 3D structural variations, such as Moho topography.

Unlike the Pn amplitude, the L_g amplitude is quite stable across the KNET. This suggests that the amplitude of Pn is much more sensitive to smaller scale variations of crustal structure than that of the L_g phase.

Regional variations in L_g observed and synthesized at the CNET and KNET arrays

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L_g coda seismograms are synthesized as multiple SmS waves in 3-D models of the crust and upper mantle by dynamic ray tracing and summation of Gaussian beams. Results are compared with data from the CNET (Caucasus) and KNET (Kyrgyzstan) arrays, located in regions having significant crustal variations along the borders of the former Soviet Union. Ray diagrams predict weak regional variations in L_g efficiency associated with weak gradients in Moho topography in the Caucasus region. In this region, synthetic seismograms predict crustal thickness variations will have little effect on variations seen across the network. Thus, effects other than crustal thickness variations must be sought to explain strong regional variations in L_g waveforms observed from different azimuths at CNET. Ray diagrams predict much stronger regional variations in L_g efficiency in the Kyrgyzstan region. These variations correlate well with strong gradients in Moho topography along the Hindu Kush and Pamir mountain ranges. Detailed variations of waveforms across the arrays are consistent with L_g efficiency being proportional to the length and number of times SmS ray paths traverse regions of strong Moho gradient.

Regional Phase Propagation in Northern Africa and the Mediterranean

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The Mediterranean region is characterized by abundant seismicity in a complex tectonic environment resulting from the convergence of the African and Asian plates. The purpose of this study is to analyze the propagation characteristics of the high frequency regional phases Pn, Pg, S_n and L_g within North Africa and across the Mediterranean Sea. We have collected regional seismograms from North African earthquakes recorded at MEDNET, GEOSCOPE and IRIS stations in the area. A first look at the data indicates that L_g propagates efficiently to distances of 2000 km or more within Northern Africa but is effectively blocked for most paths crossing the Mediterranean. The picture for S_n is more complicated and shows no clear regional pattern. However unlike L_g, S_n is observed on some paths crossing the Mediterranean Sea. These S-wave phases (S_n and L_g) are particularly important for algorithms that discriminate small magnitude (Ms < 3.5) underground explosions from earthquakes. Many studies have shown that changes in crustal thickness and/or upper mantle velocity can change or even block the transmission of S_n and L_g, greatly complicating the problem of identifying clandestine explosions in such regions. Guided by our empirical data, we make use of 2-D modeling codes to better quantify the types of structures and lengths of paths within those structures, that block these regional phases.

This research was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract number W-7405-ENG-48.

Interpretation of Crustal Phase Characteristics in Iran and the Surrounding Region Determined from ILPA Data

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The presence or absence of crustal phases such as S_n and L_g at the Iranian Long Period Array (ILPA) show a complex pattern in Iran and the surrounding region. A few degrees of azimuth may mark the boundary between an area where a phase is present and where it is absent. Previous work has identified the southern Caspian region as an area of poor S_n propagation. This study confirms that result and also identifies southeastern Makran, part of the Iran plateau, and part of the Zagros region as areas where the S_n phase is absent. In general, lack of an S_n phase can be associated with paths crossing regions of Quaternary and Tertiary volcanism. L_g propagation is present over most of Iran with the exception of the Zagros region between the Oman line and Qatar. This is an area with extensive mobile infra-Cambrian salt. Other regions identified with no L_g phase are the Caspian and Black Sea areas, which have been noted by other workers.

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