Jan. 28, 2010 final version

Active Seismic Sources within IRIS: Report from the IRIS committee exploring an Active Source Facility

Executive Summary

The decline in the number of active-source experiments over the past decade can be traced to a number of factors, but the cost and technical hurdles of mounting an active-source experiment are key factors. It requires substantial technical expertise to determine which seismic source to use, to obtain permits for using the seismic sources, and to carry out the actual experiment. Unlike passive experiments in which PASSCAL provides all equipment, and in many cases technical expertise in the field, seismic sources are currently unsupported by IRIS in any way. This places the burden on the PI to independently obtain seismic sources, funding for their use, and permits. This makes the financial and technical hurdles for active-source experiments considerably greater than for passive experiments.

It is also clear that there is conitinuing demand for active-source seismic imaging for traditional earth structure investigations, and a growing demand for shallow hazard, groundwater, neotectonics and climate studies. The PASSCAL Geode systems are heavily subscribed, and we anticipate that demand for these instruments will only increase further. The Texan instrument use is punctuated by heavy use for short periods of time followed by lengthy periods of inactivity, but it is not known how much the technical and financial hurdles affect this pattern. What is clear is that these active-source seismic systems are crucial for studying the Earth's crust in tomography and seismic reflection experiments, when used in conjunction with trenching and drillhole studies, and with geologic mapping efforts. The high resolution investigations are often naturally complemented by ground penetrating radar (GPR) investigations.

IRIS can take some steps to help facilitate active-source seismic experiments with only modest costs. This document outlines the conclusions reached by a committee appointed by PASSCAL to examine the role that IRIS should play in supporting active-source experiments. The conclusions were drawn using written input from the active-source community, from a meeting of the active-source committee at the Seismological Society of America meeting in April, 2009, and from meetings with the active-source community at the Geological Society of America and the Society of Exploration Geophysicists annual meetings in fall of 2009.

To help support and facilitate active-source work within the IRIS community, IRIS should:

Purchase mechanical sources (accelerated weight drops), additional Geode instruments, and a GPR unit so that a PI can obtain a complete system from IRIS for 3-D shallow seismic work complemented by shallower radar imaging.

To facilitate high-resolution seismic experiments, PASSCAL should have a turn-key seismic acquisition system that includes a seismic source to use in combination with the Geode multi-channel recording systems. Weight-drop sources with ~100 lb weights that are mounted on trailer hitches can be purchased for about $10,000 for a vertical-only source and about $22,000 for a multi-component source. Larger, trailer-mounted sources with ~500 lb weights can be purchased for $40,000-$50,000. These sources are easy to use and require minimal training and maintenance. The 100-lb weight drops can consistently image to several hundred m depth; the larger, trailer-mounted devices can image to depths of a km or more. PASSCAL should initially purchase a hitch-mounted weight drop source for both vertical and horizontal modes, and if demand is seen, they should purchase a larger, trailer-mounted weight-drop source. This purchase could significantly increase the number of researchers who could carry out seismic imaging experiments by removing the technical hurdle of renting and interfacing separate recording and source systems. In addition, there is interest in 3-D imaging of shallow structures, which will require the addition of more Geode channels to bring the total to about 1000 channels.

We also recommend that IRIS acquire a GPR system as a complement to the high resolution seismic systems. Radar imaging is particularly useful for neotectonic, groundwater, and archeological studies. Commercial units can be purchased for ~$25,000.

PASSCAL technician to facilitate seismic sources (point of information).

It would be extremely useful for a PASSCAL technician to serve as a point of information for mechanical seismic sources (vibrators, weight drops) and help PIs get field experiments started, as they currently do for recording systems. Specifically, this person:

1) Would be familiar with what seismic sources are available within the research and industry community, and could advise PIs on what sources are best suited for a given experiment. This function largely could be accomplished by the technician attending the annual SEG meeting to keep abreast of the newest sources and becoming familiar with potential contractors.

2) Would be familiar with and could advise PIs on the logistics of shipping and safely using seismic sources, and advise on obtaining insurance (bonds) and permits required for this work.

3) Would serve as a point of information for renting seismic sources, and perhaps negotiate agreements with providers of seismic sources on behalf of the IRIS community.

4) Would be available in the field to get active-source experiments started. Specifically the PASSCAL technician would need to interface the recording system with the seismic source and to train PIs and students in the use of small seismic sources (weight drops, mini-vibrators).

IRIS Support for the Texas proposal for an explosive-source facility.

The University of Texas, El Paso, and Texas A&M University are currently developing a proposal for retaining and developing expertise for explosives work in the research community. IRIS should be active in supporting this initiative. We have included a draft paper outlining this proposal as an addendum to this report.

Costs to PASSCAL/IRIS:

Jan. 28, 2010 final version

FTEs. If our proposal is implemented, we estimate that it will require about 2 PASSCAL technician FTEs to service the additional Geode recording systems and to serve as an expert on seismic sources. Currently the 240 Geode channels require about ½ FTE of technician time; increasing to 1000 channels would increase the technician time devoted to Geodes, but not in a linear fashion. Experiments would likely use more channels, which would only slightly increase the preparation and shipping over current usage. The main increase in personnel time would be for additional experiments and for servicing the additional channels.

Capitalization costs. The total capitalization costs for the initial equipment we recommend would be about $53,000, plus the cost of additional Geode channels. These and additional Geode costs are:

1. hitch-mounted, tilting weight-drop seismic source - ~$22,000.
2. radio trigger system for use with vibrators or weight drops - ~$6000.
3. ground-penetrating radar unit - ~$25,000.
4. additional Geode recording channels ~$1200/channel in increments of 24.

We estimate that this equipment would incur ongoing maintenance costs of about $6,000/year for the seismic sources and radar unit, and about $10/channel/year for the additional Geode channels.

Jan. 28, 2010 final version

Introduction: The Decline in Active-Source Experiments and New Opportunities

There has been a substantial decrease over the past decade in the number of active-source experiments being funded and carried out by IRIS members. In particular, crustal-scale experiments that utilize hundreds or thousands of channels to record large seismic sources, usually explosives, have been limited in recent years.

One reason that active-source seismic experiments are becoming less common is the difficulty in funding and carrying out this work. Passive experiments require only recording systems to be installed. Because the costs of purchasing and maintaining the recording instruments now reside almost entirely in the IRIS budget, the PI of a passive experiment only has to fund deployment costs. Technical support comes with the recording instruments in the form of PASSCAL technicians, with the PI only paying travel costs. The IRIS model has effectively shifted instrument costs and technical support onto PASSCAL, resulting in dramatically reduced costs and technical barriers for carrying out a passive seismic experiment compared to the pre-IRIS days. The result has been a substantial increase in the quality, complexity and scope of passive experiments, and a dramatic increase in the number of PIs capable of carrying out large seismic experiments. The often-mentioned result is a “democratization” of seismic work that has greatly increased the size of the IRIS community and strengthened IRIS as an organization.

The development of the IRIS pool of recording instruments has had less of an effect on reducing the costs and logistics of active source experiments because seismic sources, which often represent the largest cost and most difficult technical issues in an experiment, are currently not supported in any substantial way by IRIS. An example might be a typical crustal-scale tomography experiment that involves 2000 “Texan” recording instruments and 20 large dynamite shots. In the High Lave Plains (HLP) experiment, for example, deployment costs for the 2600 Texan instruments was approximately $80,000, mostly in travel and vehicle costs for the 67 students and volunteers deploying the instruments. This deployment cost is similar to those for large passive experiments, and made use of PASSCAL instruments and technical support. The sources for HLP were modest, consisting of 15 large shots. Nonetheless, it cost approximately $160,000 to drill the shotholes, purchase the explosives, and detonate the sources. The explosives work used no PASSCAL equipment or personnel. Thus, the bulk of the active source experiment’s field cost, and most of the logistical and permitting effort are not aided by PASSCAL instrumentation or technical support. Seismic sources also require technical know-how for the experiment to be done safely and correctly. The result is that active-source experiments are costlier and involve more logistical issues for the PI than passive experiments. This increased cost differential between passive and active-source experiments has created a higher hurdle for getting active-source experiments funded.

An example on a smaller scale also illustrates these issues. A typical, 2-week high-resolution seismic imaging experiment with a mini-vibe source will use about 240 channels of PASSCAL Geode recorders. The mini-vibe source, however, will need to be rented and a technician/mechanic will be required to drive the vibrator. The recording portion of the experiment, making use of PASSCAL instruments, will cost about $20,000 for travel for the 6 or 8 person field crew. The mini-vibe source, however, will cost about $25,000 in rental, $3000 to $6000 in shipping (or mileage) costs to get it to the experiment site, and about $3000 in technician/mechanic salary. Thus, the mini-vibe source alone will cost about $31,000 to $33,000 for the experiment, which more than doubles the cost of the experiment.

The more substantial impediments to carrying out active-source experiments are the expertise needed to permit and use the seismic sources, and to interface the seismic sources with the recording system. The latter issue can be substantial for vibrator sources, which require radio triggering, accurate timing, and correct phasing of the vibrator baseplate with the input sweep signal. It is not uncommon for experienced technicians using a new vibrator source to spend several hours carrying out this interface work. Currently, most vibrator operators (mechanics) do not have experience with the Geode recording systems, and most PIs do not have experience with maintaining vibrator sources. These issues make it difficult for a PI without substantial experience to carry out an active-source experiment.

There is an opportunity in the next few years for IRIS to support the rapidly-growing interest in shallow imaging (to < 1 km depth) within the IRIS community. Shallow seismic reflection imaging is becoming increasingly important in groundwater, hazard and climate studies. In conjunction with geologic information such as mapping, coring and trenching, many studies incorporate shallow imaging to delineate aquifers, determine the subsurface geometry of faults, and characterize the shallow stratigraphy. These studies are increasingly moving toward 3-dimensional experiments that require large numbers of channels. Nearly all of this high-resolution seismic work makes use of Geode recording instruments like those owned by PASSCAL, as many PIs carrying out high-resolution seismic work own systems that are nearly identical to the IRIS systems.

High-resolution seismic imaging is also becoming increasingly important from an educational perspective. The methodology for shallow seismic imaging is nearly identical to that used for deeper imaging for resource exploration, and there is a growing demand for exploration geophysicists as the existing workforce retires. Shallow seismic imaging projects therefore provide a training ground for future industry workers, at a cost that is much more affordable than industry-style imaging to 8 or 10 km depth. Summer geophysics field camps such as SAGE, or Colorado School of Mines', would likely make use of IRIS instrumentation.

Given these problems and opportunities, the question arises as to how IRIS can facilitate active-source seismic work by providing seismic sources and/or technical expertise like they currently do for recording systems. Traditionally, IRIS has not provided any significant funds or technical support for seismic sources, in part because of concerns about liability issues. In this document we propose ways in which IRIS can assist PIs carrying out active-source experiments through an initial, modest "Source Facility".

Active-sources – a review of source types and availability

Currently, active seismic sources can be divided into 4 broad categories: 1) small, high-resolution sources; 2) mini-vibrators; 3) large-scale vibrators; and 4) explosives. In addition, there are several other experimental or non-seismic sources that should be considered within the context of a seismic source facility. The descriptions of these sources, current facilities, rough costs, and permitting issues for each of these sources are outlined below.

Small seismic sources (accelerated weight drops, hammers, guns) – figure 1

High-resolution seismic work has made use of a surprising variety of small seismic sources for shallow work. Sledgehammers, shotguns, machine guns, small weight drops, pile-drivers, crate-sized vibrators, enclosed marine sparkers and airguns, piston sources, earth tampers (mini-sosie), and jackhammers have all been tested as seismic sources. Most of these devices are small enough to be shipped as freight, or are mounted on a small trailer that can be towed to the experiment. Their cost is modest, with small weight-drop sources costing about $10,000 for the simplest system to about $50,000 for large systems. A number of private companies and academic or government institutions own these sources, although few companies offer rentals.

The committee and PASSCAL personnel agreed uniformly that ***PASSCAL should not support any seismic sources that involve firearms***, neither off-the shelf weapons, nor specially designed firearms for seismic work. PASSCAL can direct prospective users to groups with experience with firearm sources, for example personnel in the USGS office in Golden, Colorado, or the Kansas State Geological Survey.

Among the small sources, the simplest to obtain and operate are hitch-mounted or trailer-mounted accelerated weight drops. Two sizes of weight drops are available: 1) small, hitch-mounted weight drops that can be shipped in standard freight and can be attached to the trailer hitch of a pickup truck; and 2) trailer mounted weight drops that are towed to a site behind a truck, van or SUV. A hitch-mounted weight drop generally has about a 100-pound weight that is accelerated downward with a large rubber band (essentially a large sling shot) or with compressed gas (nitrogen). They are available using hydraulics to lift the weight, which adds the noise of a gas motor, or quieter electric-powered devices that run on battery power. Hitch-mounted weight drops can image to 300 to 500 m depth, while larger, trailer-mounted weight drops can image to greater than 1 km depth in good conditions. These sources have few liability or operational difficulties, and users can be trained in less than an hour. As long as the PIs and operators use common sense, such as keeping hands away from exposed moving parts and only using the sources on solid, nearly level surfaces, there are few dangers to using these sources.

[Recently, some very large weight drop sources have been developed that are mounted on large trucks and accelerate weights of as much as 2000 lbs. This report did not consider these large weight drops, as we felt that mini-vibrators or full-sized vibrators would be more suitable for imaging to several km for research purposes.]

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Mini-vibrators (figure 2)

In the past decade, small, high-resolution vibrators (mini-vibes) have been developed for shallow seismic imaging to depths of one or two km. These small, truck-mounted or trailer-mounted vibrators sweep at frequencies of 10 to 500 Hz, although in practice 250 to 300 Hz seems to be the effective high frequency limit because of energy transmission and vibrator output. The devices weigh 4,000 to 14,000 lbs and are mounted on a trailer, on the back of a small truck, or on a 4-wheel-drive buggy. The advantages of mini-vibes over weight drops are that vibrators give you better control over the source frequencies, and vibrators work better in noisy, urban environments because they can spread the source effort over a substantial time (30 seconds) to reduce the effects of random noise.

Most of these vibrator sources are made by Industrial Vehicles International (IVI) of Tulsa, Oklahoma. In addition there are at least three different groups within the academic/government research community who have high resolution vibrators that are potentially available for rental or collaborative work:

1. The NEES (UT, Austin) IVI Minivibe known as “Thumper”
2. The New Mexico Tech (Socorro) IVI Minivibe operated by Cathy Snelson
3. The University of Nevada Las Vegas IVI Minivibe operated by Barbara Luke
4. A range of rental vibrators available from the IVI in Tulsa OK. (http://www.indvehicles.com)

Each of these vibrators has different configurations in terms of hold-down weight, mounting platform (truck versus trailer), frequency range, and ability to switch from vertical to horizontal modes by changing the actuator. NEES (UT Austin) has educational grants available that cover some or all of the costs of using their vibrators for educational purposes. These grants are competitive, however, and funding cannot be assumed in advance.

Mini-vibrators need to be properly permitted and insured, and they require maintenance commensurate with a specialized truck. This maintenance includes both mechanical and electrical issues. The machines have the capability of damaging road surfaces and disturbing or damaging adjacent land and structures through prolonged vibration. The machines also involve some risk, in that there are high-pressure hydraulic hoses and exposed moving parts that can cause injury. As with weight drops they are generally safe to use so long as the operator uses common sense. To our knowledge, there have been no accidents in the academic/government research community that have led to lawsuits or injury requiring hospitalization. This safety record, however, may reflect in part that the research groups currently using these devices are experienced or are working with experienced personnel. For maintenance, a good mechanic is needed to maintain the equipment, or the equipment can be brought back to the manufacturer for periodic maintenance.

Rental of mini-vibrators generally involve a daily or hourly use fee, plus a mileage charge. The devices are often shipped on tractor trailer trucks, which can involve significant shipping costs. Rentals generally cost about $25,000 for a month of work, including time for shipping to the site. A one-month rental generally allows about 20 days of actual work, because shipping will often consume a few days on each end of the experiment. In addition, typical shipping charges within the U.S. are $3000 to $7000 depending upon distance. Renters often request an operator, or are required to have an operator, with the vehicle. In these cases, the renter usually pays the operator salary, overtime, and travel expenses, which can amount to about $5000 for several weeks of work.

There have been some issues regarding availability of rental mini-vibrators from the manufacturer (IVI), specifically that there are higher-paying, high demand private sectors customers who seem to have priority over academic users. However, IVI does have a rental fleet of several small vibrators with various weights and mounted on various vehicle types. Single mini-vibes are owned by NEES, UNLV (Barbara Luke), and New Mexico Tech (Cathy Snelson), each of which is a different configuration of vehicle (trailer, truck) and weight. The NEES and UNLV vibrators have a technician who comes to the field to operate the device (PI pays salary, per diem and overtime). The NEES operator has little or no experience with recording systems; the current UNLV operator has some experience with Geode recording systems.

Large vibrators

Large, industry vibrators have been used in the academic community for over 40 years. These vibrators have weights of 20,000 to 80,000 pounds and sweep from frequencies of 6 to 150 Hz. They are often used in sets of 3 to 8 sweeping simultaneously to image to Moho depths or deeper.

The only such vibrators we are aware of in the academic community are the “T-Rex” and “Liquidator” at the NEES facility in Austin, Texas. These NEES vibrators, however, are specialized in that T-Rex can vibrate on any axis to collect 3-component data. Liquidator has been modified for ultra-low frequency work, which limits its upper frequency range to about 100 Hz. Thus, the two vibrators are not designed for “production” seismic reflection profiling, and would be more expensive than more normal vibrators for routine production work. In the past few months, the NEES facility (UT, Austin) added both a shear-wave and a P-wave vibrator, both of which are more suitable for routine production work; we are not aware of anyone who has yet used these devices. Anecdotal information suggests that the large NEES vibrators are not well suited to crustal scale seismic investigations.

IVI also manufactures large vibrators, and may have them available for rent. We are not aware of any researcher who has rented large vibrators from IVI, but presumably a rental agreement could be negotiated.

More commonly, sets of large vibrators can be rented, with operators, from geophysical contractors who normally provide the service to the petroleum industry. The Consortium for Continental Reflection Profiling (COCORP) and other research projects such as CD-ROM used industry seismic crews for acquisition of crustal-scale seismic reflection profiles. Because the vibrator costs are the largest part of an experiment, it is generally easier to rent an entire seismic crew for an experiment, rather than renting only the sources and using PASSCAL recording systems deployed by students.

Prices for industry seismic crews need to be negotiated for each project, and will vary depending upon number of vibrators and recording channels. The prices also vary considerably depending upon current demand by the petroleum industry. The costs are roughly $25,000 or more per day of work, so a month-long project can approach the $1 million price range.

Jan. 28, 2010 final version

Explosive Sources

Explosives work can be carried out at several scales ranging from numerous small (10 to 100 pound; 5 – 50 kg) shots in seismic reflection imaging to large (1000 to 10,000+ pound; 500-5000+ kg) shots for crustal- or lithospheric-scale work. The research community rarely uses small shots, as vibrators or weight drop devices provide safer alternatives for most work. Large explosive sources, however, cannot be replaced easily by vibrators due to range limitations.

Crustal-scale explosives work involves drilling 100 to 200 foot deep holes, often cased with steel or pvc, usually by a local well driller. The blasting agent (typically an ammonium nitrate compound) is usually pumped as a slurry into the hole. The explosive is primed for detonation by placing blasting caps and boosters (sticks of dynamite) in it, and is tamped by filling the top of the hole with drill cuttings and water. The charge is detonated, usually in the quiet of the night, using an electric “shooting box” connected to the blasting cap wires. The shooting box is synchronized with a GPS clock to provide accurate, absolute firing times that correspond to event time windows for which the recording systems are pre-programmed to start. Newer triggering devices use a gas-filled plastic tube with a diameter about the same as a wire, with the charge being detonated by providing a spark to the gas. The gas devices are predominant in the construction industry because they eliminate the possibility of accidents due to induced currents within the wires of the blasting cap. Gas triggering devices are not suitable for seismic work, however, because there is some uncertainty in the firing time because of delays in the propagation of the spark down the gas-filled tube. The seismic industry is thus the main user of electric blasting caps as the construction industry has moved to gas triggers.

There are surprising technical issues to related to maximizing the output of an explosive charge. For example, it is apparently more effective to use a wider-diameter drill hole and a shorter explosive charge than to use a small-diameter drill hole that requires a longer charge. There are also different ways to tamp the hole and where to place the blasting caps to maximize the energy output.

It is uncommon that there are significant liability issues associated with explosives work in the seismic research community, largely because most research work places shots in remote areas away from structures. The community has developed guidelines for shot size and distance from the nearest building to avoid damaging nearby structures. However, shot holes have caused artesian flows, slumping of land, and minor damage to structures. These events have required up to $80,000 to repair in academic-government projects, which makes liability insurance a necessity, and a clear chain of responsibility a requirement for explosive source experiments.

In the 1980’s and early 90’s most of the explosives work in the research community used to be carried out by USGS personnel who were part of the Menlo Park Crustal Studies Group. This group has largely been disbanded, and most of the shooting experts have retired. Presently, most academic projects that involve explosives work use Steve Harder from UTEP as their explosive expert, although Cathy Snelson of New Mexico Tech has also done some of this work.

Other sources.
In addition to the “standard” seismic sources described above, there are several other sources that IRIS should be aware of:

Innovative research seismic sources

Another category of seismic sources that IRIS should keep abreast of are those that are being developed within the academic community. For new sources, it may benefit the research community for IRIS to help in the development and maintenance of seismic sources.

An example of a seismic source that may prove applicable to seismic research is the “shaker” source currently being developed by NEES (UCLA) and the Carnegie Institute of Washington These are large vibratory sources that were originally designed for shaking buildings for engineering tests, but are being tested for seismic research. The NEES source consists of a pair of large (1000 to 2000 pound) weights that are rotated synchronously about off-center axes. Their rotation creates a strong, directional, horizontal oscillation, and they can be run at a single frequency or swept through a range of frequencies from 1 to 15 Hz. The device is not portable – it is bolted to a 14-foot by 14-foot, 2-foot thick cement pad that must be constructed specifically for the experiment. The device was used for measurements of temporal changes in phase velocity at Parkfield (Paul Silver and Fenglin Niu, and is currently being used in the Cascadia region to look at temporal changes in wave speed and reflectivity associated with episodic tremor and slip (ETS). Early tests in Cascadia indicate that the signal was visible to at least 60 km, and possibly to 90 km distance. If the device is found useful in Cascadia, it has the potential for a range of velocity measurement and imaging experiments. Carnegie Institute recently commissioned the construction of a larger version of the shaker source, primarily using private funding.

Because this is a source developed in the research community, there is no commercial market for it at present. For now the devices are available from the NEES facility in UCLA and from Carnegie Institute in Washington, DC. Other IRIS members may be interested in the development and use of this device. As such, IRIS may in the future want to venture into helping to maintain and develop this and other research seismic sources.

Ground-Penetrating Radar (GPR) and electrical imaging devices

IRIS has concentrated on seismic work, but ground penetrating radar (GPR), Electromagnetic (EM) and magnetometer systems should be considered for future purchases by PASSCAL. The GPR methodology is nearly identical to seismic reflection imaging except that electromagnetic waves rather than seismic waves are used. The field procedures and data processing are nearly identical to shallow seismic work, and some researchers typically use a combination of GPR and shallow seismic in their work. Data are often processed using standard seismic reflection processing software. The characterization of shallow strata, particularly aquifers and shallow faults, with a combination of electromagnetic and seismic methods can be far more effective than using seismic alone.

In the same category are EM devices and magnetometers. Both of these use electromagnetic waves for imaging the shallow strata.

All of these electromagnetic imaging devices are readily available on the market for a modest cost. GPR systems cost about $25,000 for a basic unit. An EM31 is available at a cost of about $10,000. Magnetometers cost about $5000. All of these devices have relatively minor maintenance costs associated with them. The availability of GPR units through IRIS could significantly increase the use of these instruments in the academic community, and could expand the IRIS research community.

Marine sources

There are a number of marine seismic sources that are commonly used by IRIS member institutions, such as chirp systems, unibooms, sparkers and airguns. In keeping with the IRIS tradition of providing only land recording instruments, the committee did not see a need for PASSCAL to support marine seismic sources. Furthermore, PASSCAL currently does not have any instruments for recording in the marine environment. Marine sources are readily available for rental from a number of institutions and companies, often as complete systems that include the recording capabilities.

Steps Toward a Seismic Source Facility

At a meeting at the Seismological Society of America meeting in Monterey in April, 2009, the seismic sources committee had extensive discussion of IRIS involvement in the purchase and maintenance of seismic sources for active-source experiments. The committee had already read the input from the community in response to a questionnaire sent out several months earlier. The committee discussion focused on the four major categories of seismic sources outlined above, and concluded that IRIS should deal with each category in different ways.

Small active-source equipment (accelerated weight drops)

The committee felt that PASSCAL should initially purchase a hitch-mounted weight-drop source so that a turn-key acquisition system is available for shallow seismic imaging. If demand warrants, a larger, trailer-mounted weight drop can be added. Furthermore, the number of Geode channels should be increased from 240 to about 1000 to facilitate 3-dimensional imaging and allow for more experiments.

The committee believes that the availability of a turn-key PASSCAL system would significantly increase the number of researchers willing to undertake shallow seismic reflection and refraction imaging. Relatively small, inexpensive weight-drop sources have wide applicability in shallow seismic imaging. Modern sources can be used for both P-wave (vertical) and S-wave (horizontal) modes by tilting the device. Having a weight-drop source as an accompaniment to the Geode systems would provide researchers with a complete seismic system for imaging up to one or two km depth. Unlike vibratory sources, a weight-drop source requires nominal training for proper use and maintenance, and would not require a technician to be with the device in the field. Aside from a modest capitalization cost (~$25,000), there would be relatively small maintenance costs associated with these devices (~$2000/year?). Interfacing these weight drops with the PASSCAL Geode recording systems is straightforward with a simple accelerometer, a contact-closure switch, or radio triggers. Radio triggers cost about $6000 for a robust, durable system with a long radio range (1 to 2 km).

The number of Geode channels needs to be increased to about 1000 for two reasons. First, the current 240 channels of Geode equipment are heavily subscribed for both research and educational purposes. The addition of a weight-drop source to the PASSCAL equipment pool will, we believe, move many of the educational uses from a simple classroom demonstration to a useful data collection effort for undergraduate or graduate student theses. It will also enable a much larger set of researchers to collect shallow seismic reflection data in conjunction with geologic and other geophysical data. This will increase the demand on the PASSCAL Geode systems. Secondly, characterization of shallow aquifers, faults and stratigraphy is ripe for the application of 3-dimensional seismic imaging. For effective 3-D imaging, however, a large number of recording channels is needed; even 1000 channels is a small relative to modern industrial surveys.

Small vibrators

Given the number of mini-vibe sources already in the research community, the committee is not enthusiastic about PASSCAL owning or maintaining a mini-vibrator. However, having a part-time technician's FTE devoted to understanding and using these sources could substantially lower the barrier for researchers to use these systems.

The committee felt that the best role for IRIS would be to negotiate agreements with the owners of these devices to easily allow academic users to rent them. Having a PASSCAL technician who is familiar with using mini-vibes and interfacing them with the Geode recording systems would facilitate novice PIs to use them effectively. This PASSCAL technician could also familiarize themselves with permitting issues so that they can advise PIs about that process.

Perhaps the most difficult technical issue in using mini-vibe sources is to interface the source with the recording system. The triggering, usually by radio, must be enabled so that the source and recording system are synchronized. The pilot sweep used in the min-vibe needs to either be recorded in the source truck or sent via radio to the recording system. Although simple in principle, it often takes several hours for a trained technician to get the source and recording systems interfaced for the first time. A PASSCAL technician who is trained to do this would be necessary for PIs to use a mini-vibe source with the PASSCAL Geode systems. This technician could come to an experiment for a few days to get the experiment started, similar to the technical support provided by PASSCAL for passive experiments.

Industry-style vibrators

The committee feels that the demand for large vibrator sources is low (the last US academic vibrator survey was done in 1990), and that PASSCAL does not have the financial resources or personnel to purchase and maintain a fleet of large vibrator sources. The capitalization and maintenance costs of these vibrators are large, and unjustified given their relatively light usage. Large vibrator sources for crustal-scale imaging can be rented from geophysical contractors on an as-need basis.

However, PASSCAL could help individual researchers by serving as a source of information for PIs. Specifically, having a PASSCAL technician familiar with available equipment and contractors could be useful for advising PIs within the IRIS community. This could be accomplished by attending the SEG meeting on an annual basis to keep abreast of new developments in instrumentation and services, and to maintain contacts with industry representatives.

Explosives

There are two organizations that have expressed an interest in serving as contractors for large explosions for seismic work. First, Steve Harder at UTEP is already involved in a number of experiments, and will continue to be available for future work. His group could be expanded if demand increases. Secondly, New Mexico Tech's Energetic Materials Research Test Center (EMRTC), which is fortuitously housed in a building adjacent to the PASSCAL facility, has indicated an interest in serving as a contractor for explosives work within the research community. EMRTC personnel have stated that they would want to handle the complete process, including permitting, if they were to carry out this work. EMRTC personnel would require some training in understanding how the seismic community uses explosives, but it is anticipated that this learning process would not be extensive. The committee initially felt that the best option for PASSCAL is to have discussions with these groups, and potentially negotiate open contracts with them to pave the way for university researchers to utilize these groups to carry out explosives work.

Subsequent to the instrument committee meeting at the SSA meeting, the University of Texas (Steve Harder at UT El Paso and Kate Miller at Texas A&M, with involvement by Cathy Snelson at New Mexico Tech) has indicated that they plan to move forward with a proposal to NSF for funding a seismic explosives facility. The goals of the facility would be to preserve and expand existing expertise in the research community for carrying out large explosive shots. The proposal calls for upgrading of equipment (shooting boxes), funding key personnel salaries, and providing explosives training courses in both the academic and industrial communities. The total cost of this proposal was initially estimated to be about $220,000/year. Because the state of Texas has a substantial interest in maintaining expertise within the seismic industry, the state university system may be willing to accept some or all liability for experiments using the source facility as the explosives contractor.

The committee encourages IRIS to endorse and support this proposal effort in any way they can.

Other Sources

As mentioned before, the committee felt that ground-penetrating radar and electromagnetic (EM and magnetometer) systems provide a strong complement to seismic reflection imaging systems for shallow characterization, and that PASSCAL therefore should consider the purchase of GPR and EM equipment and a magnetometer.

We anticipate that these instruments will be widely used in conjunction with the shallow seismic imaging equipment in groundwater and active fault studies, and would also see use in archeological, climate and glacial studies.

A logical starting point would be the purchase of a ground-penetrating radar system. These are relatively simple to use and maintain, and the initial capitalization cost would be about $25,000.

PASSCAL should also continually monitor the development of other potential sources such as the UCLA and Carnegie "Shaker" counter-rotating source. If such sources are demonstrated to be useful to the IRIS community, PASSCAL should examine how to support and encourage the use of these sources.

Source Costs in PI Budgets

Although the above plan works toward solving the logistical issues of making sources more widely available to the active-source community, and it especially addresses the needs of the shallow imaging community, it fails to address perhaps the primary issue causing the decline in large active-source projects - financing.

The PASSCAL instrument pool has dramatically reduced the cost of passive-source experiments by removing the cost of purchasing and maintaining instruments. Many of the large passive experiments that utilize 100+ broadband seismometers are possible only because the instrument costs are borne by PASSCAL outside of the individual proposals. In a similar manner in other fields, the large facilities such as telescopes, particle accelerators and UNOLS ships have moved major equipment costs off of individual proposals and onto the facility. The active-source community thus remains hampered by the necessity of having relatively large budgets to rent, purchase or operate seismic sources.

One model favored by some members of our community but not supported by most of this committee is to have IRIS (or another organization) make seismic sources available at no cost to PIs. The comparison is made to the NSF research ships or with the current passive experiments, in which the PI's proposal includes only the PI's institutional costs; a matching request for the instrument facility (both source and recording) is funded from the "facilities" (e.g., IRIS) budget. This model would allow any PI to carry out an active-source experiment because IRIS would provide all of the equipment and technical support, and the facility would reduce the costs of the PIs' active-source proposals so that they are more in line with current proposals for passive experiments. This would be similar to a research ship, which comes with on-board technicians that relieve the PI from the burden of having to provide technical expertise.

The argument for the all-inclusive source facility is that it would make active-source work readily available to any researcher, regardless of their technical expertise. The immediate effect would be to enable an active-source component for many of the passive experiments, which could dramatically increase the resolution of the imaging. It is now standard that a passive experiment includes tomography, attenuation tomography, receiver function analysis, and noise cross-correlation into most experiments. A hassle-free source facility would likely add active sources to this mix for most experiments, at least for calibration purposes if not for extensive imaging. This also could potentially grow the active-source community, and dramatically increase the effectiveness of seismic experiments, by providing a relatively hassle-free option of combining active-source work into most any major experiment.

The complication to an all-inclusive source facility is that it would be difficult to predict the costs for the coming year, and one could foresee the active-source work consuming a large part of the IRIS budget. Specifically, the ready availability of active seismic sources would likely result in PIs requesting far more source points than they currently use. The effect would be much like what has happened to the broadband community: where once it was standard to request 20 broadband instruments for a major experiment, it is now routine to request over 50. This has significantly increased the demand on, and capitalization cost of the broadband instrument pool at PASSCAL. One potential model for a source facility would be to initially fund it at a level commensurate with the average cost of sources over the past few years.

An increase in the number of source points in an experiment could, however, be an opportunity for the research community. Continuing the comparison with broadband instruments, the availability of more seismic sources in an experiment could dramatically increase the effectiveness of the experiment and make new, as yet untried, work possible.

On the other hand, IRIS needs to be aware of the problems currently plaguing the research ships, and to some extent the early implementation of Earthscope. The facilities are consuming such a large fraction of the total budget that it has reduced the money left to fund the science. In the oceanography community, many of the research ships are idle for a significant fraction of the year due to lack of demand. IRIS must be careful to not commit so much money to seismic sources that it negatively impacts their current mission.

If demand for seismic sources increases in the near future this funding model may be worth further consideration, at present we feel that the demand is not yet sufficient to warrant taking any steps in this direction.

Conclusions

In summary the committee recommends that IRIS:

1. Purchase at least one accelerated weight drop source
2. Increase the number of Geode channels to at least 1000
3. Acquire a ground penetrating radar unit as a complementary imaging technology to seismic reflection in shallow studies
4. Make 2 PASSCAL FTE technical positions available to operate and maintain the above and to
    a. Provide PIs advice and help in permitting active source experiments
    b. Be technically capable of operating the PASSCAL Geode system with the mini-vibrators available from NEES, UNLV, NMT, and IVI
    c. Be familiar with the NEES, UNLV, NMT, and IVI rate schedules

   d. Be familiar with contractors offering large vibrator/reflection recording services
5. Endorse and support the Texas proposal for a national seismic shooting facility

Figures

Figure 1a (Left): hitch-mounted weight drop. The weight drop has a ~100-pound weight that is lifted about 2 feet off the ground and released. A large rubber band stretched across the top of the weight (the white, inverted-V) accelerates the weight downward and keeps the weight from “bouncing” when it hits the ground. Behind the weight drop, the small gas motor and hydraulics can be seen in the front right front corner of the pickup bed. The metal plate prevents road damage; yellow rope pulls the plate along the ground when the truck moves forward. Triggering of the seismograph is done either with an accelerometer mounted in the road plate (note wire coming out) or can be made using an electrical connection between the weight and the road plate. The source routinely images to 300 to 500 m depth. This device is owned by a consulting company in Los Angeles.

Figure 1b (Right): trailer-mounted weight drop that operates in the same fashion as the hitch-mounted weight drop but uses a ~550-pound weight. The source images to as much as 1 km depth. This device is custom-built at Boise State University.

Digipulse AWD II Model 750T

Figure 1c. Another example of a trailer-mounted weight-drop seismic source that is currently manufactured by Geosurvey Systems Inc. The system has up to a 1080-pound weight, with operation similar to Boise State’s system pictured above (the elastic band is within the red metal protector. The weight is shown in its “travel” position – it is rotated to a vertical position when being used.

Jan. 28, 2010 final version

Figure 2a. Trailer-mounted mini-vibe seismic source. The actuator is between the wheels, and the computer that controls the sweeps is in the cab of the pickup. The white box is the diesel motor and hydraulics. The large white cylinders in the back are water tanks to provide additional weight. In this picture the actuator is in the down position, lifting the wheels off the ground. This vibrator has a 4500-pound force. The source images to 600 to 800 m depth. This vibrator was built by IVI (Industrial Vehicles International) and is owned by the University of Nevada, Las Vegas. New Mexico Tech is purchasing a similar vibrator.

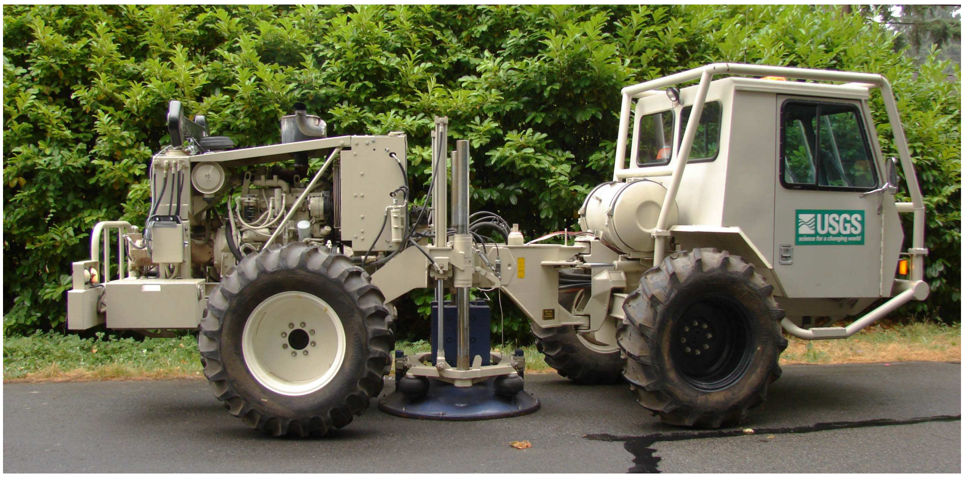

Figure 2b. Buggy-mounted mivi-vibe seismic source. The actuator is seen between the wheels. The diesel engine on the back provides power for both the hydraulics and to drive the vehicle. The computer is in the cab. The white cylinder behind the cab is the fuel tank. This is one of the largest of the mini-vibes, and generates a 12,000 pound force. In urban areas, we generally turn the power down to prevent damage to roads and shaking of nearby houses. The source images to over a km depth. The vehicle was rented from IVI (Industrial Vehicles International) by USGS personnel, who attached the magnetic sign to the side. The actuator can be changed from P-wave (vertical) to S-wave (horizontal) with about a day of work.

Figure 3a. This is a large vibrator made by Industrial Vehicles International. It has a 60,000 lb weight and can sweep from about 5 Hz to about 100 Hz.

Figure 3b. The NEES “T-Rex” vibrator at University of Texas, Austin. The vibrator is similar to the one pictured above, except this vibrator can rotate between the vertical and two horizontal directions almost instantaneously.

Figure 4. The NEES, UCLA, Shaker source. The motor at right rotates two large, off-center weights (~1000 lbs), one of which is in the solid part of the device closest to the camera and other is on the opposite side of the device. The shaker needs to be bolted to a large concrete pad. The device was originally designed to shake buildings for earthquake hazards research, but is being tested for use in seismic imaging.

Jan. 28, 2010 final version

Appendices:

1. Attendees at the IRIS/PASSCAL Committee on Active Sources Meeting at SSA, April 9, 2009

Marcos Alvarez, PASSCAL
Bruce Beaudoin, PASSCAL
Tom Brocher, USGS, Active Sources Committee member
Meng Farn-Yuh, NEES, observer
Jim Fowler, PASSCAL
Gary Fuis, USGS, observer
Alan Levander, Rice, Co-Chair, Active Sources Committee
Lee Liberty, Boise State, Active Sources Committee member
Tom Pratt, USGS, Co-chair, Active Sources Committee
Ellen Rathje, NEES, Active-Sources Committee member
Absent: John Hole, Active-Sources Committee member

2. Texas Source Facility Proposal.