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How passive data can be used to improve active land data.

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Summary

Until recently, the term "passive seismic" meant more to those interested in earthquake seismology than to anyone pursuing hydrocarbon exploration. However, recent advances in this field, including those in processing and most especially the capabilities of cableless recording systems, has enabled exploration geophysicists to benefit by using data acquired passively to improve their active records. As a result "passive" is becoming a standard aspect of active land geophysics and its expected near-future additional value is without doubt.

Currently, there are multiple techniques and views on which passive technique can best add value to final sections, and it is almost certainly the case that there is no single right way. Various groups worldwide are gathering expertise in their own specific favourite method. While the science progresses, it is likely that more techniques will be perfected. As additional experience is gained by the geophysics community it will probably become more obvious as to which methods, or group, under which circumstances are the most appropriate for each problem we want to solve.

In the meanwhile, as with all other areas of physics, the passive data collection phase must be carried out in such a way as to give operators the widest range of choices in how to use recorded data. This is not only in terms of the immediate use of the information provided but also in regard to being able to return to it at some later point and apply different processing algorithms.

In other words, recording instruments and sensors, and their method of deployment, i.e. how the system itself forces deployment to be carried out, should not subsequently limit what can eventually be done with the acquired data. In a sense, hardware should offer "uncommitted data" to the end user, that is: the data recorded is not lacking in some way due to how the system had to be used or some specification of the instrument itself, or the range of sensors that can be employed. Fortunately, some modern instruments not only allow recording of active and passive data, they also do not limit how and what data can be recorded. For example, they allow operation in a variety of environments (see Figures 1 and 2) and with a variety of sensors (Figure 3). Both these capabilities are unusual in any recording system.

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Figure 1: The same hardware used for active must be useable for passive acquisition in all environments and provide "uncommitted data".

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Figure 2: Use of hyMesh option on Sigma system to obtaining passive data in low channel density thick forest conditions, allowing high band width real time data transfer of "uncommitted data " without cables.

Figure 3: Use of high sensitivity sensor (Guralptype) with standard Sigma cable less system. A very important feature of modern instrumentation for passive is that they can handle a wide variety of sensors.

Introduction

In hydrocarbon exploration, the initial growth of the passive data industry tended to revolve around newly formed companies, or departments of existing organisations, who specialised in their own in-house developed techniques to provide bespoke services to end-users. These companies can certainly take much of the credit for bringing to the industry's attention the great potential of passive data acquisition and processing.

However, the rapid expansion of interest in what passive can do is now being driven partly by those who want to see many more contractors able to offer passive services and partly by those oil companies who need to develop their own internal capabilities to some level. These desires are being fulfilled by manufacturers of hardware that has the capability to take on the wide range of "uncommitted" recording which passive entails, and also by smaller companies who provide relevant software and/or processing services.

Unlike some previous episodes in our industry's history when novel techniques required very different and separate hardware to that used for active recording, nowadays there exist instruments which can be simply configured to take on the full range of passive, active and dual configuration recording, and still provide the all-important uncommitted data. Therefore, any company with a seismic crew, appropriate hardware and field skills can now see itself not only as capable of undertaking conventional recording but it can also become a passive data acquisition operation too.

This allows end users to combine active and passive data sets, from a simultaneous recording operation. Figure 4.

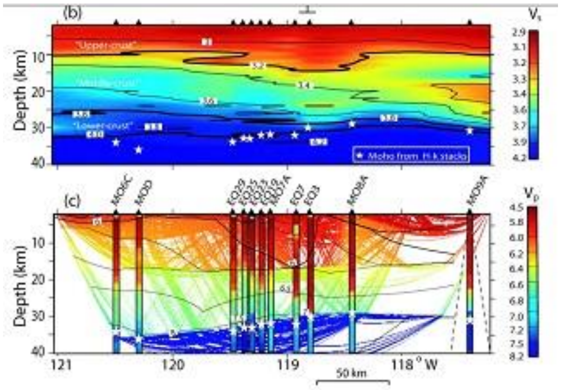

Figure 4: Combining data acquired simultaneously in active and passive recording.

Examples

There are many passive techniques that could be considered but this paper looks at only three which have already demonstrated some success in assisting in the search for hydrocarbons. Those chosen include two ways potentially of improving the quality of active data using passive recording, (one in relation to passive energy moving in the near surface and the other using passive energy generated at depth) and then we look at passive used as a direct hydrocarbon indicator.

Whereas the processing required is different in each, the instrumentation employed is the same in all cases, and is exactly the same hardware as can nowadays be used in active recording. This ability of one instrument to be used for many types of acquisition is the key to allowing oil companies to be their own passive contractors. Indeed, when reviewing new recording systems, as in other countries, some would say that it is most important to consider the capability of that new hardware in terms of how well it can handle both multiple types of active and multiple types of passive recording techniques whether 1C or 3C. It most certainly is no longer necessary to have many distinct sets of equipment to carry out these differing types of geophysics when one system can do it all.

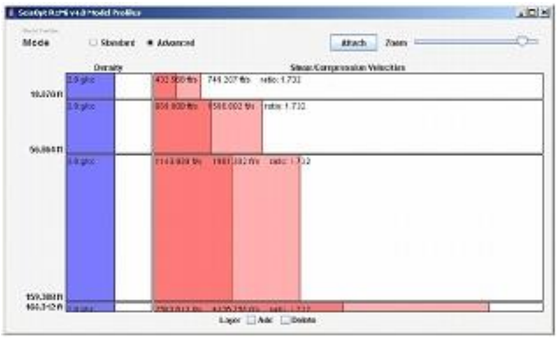

Figure 5: Velocity profiles from passive data.

Passive techniques - Improving Near-Surface Statics

We start with the two techniques which may be able to improve the quality of active data. The first tries to reduce uncertainties in the final section due to surface complexities, primarily by providing improved statics solutions. This technique is called Refraction Microtremor (ReMi) and has been used many thousands of times around the world. In fact, it is so powerful that it can be used to assist geotechnical surveys as well as those for oil and gas.

Note: whereas ReMi has many adherents, another technique which concentrates on solving surface issues, and which also has a considerable following, is called MASW (Multiple Analysis of Surface Waves). We do not look at MASW here but it is sufficient to state that any equipment capable of carrying out dual active/ReMi surveys can also be used on dual active/MASW surveys. Only the processing approach differs. ReMi requires the deployment of a short line of receivers which can be single component or 3C (Figure 6), the latter being preferred by some though by no means essential.

If the crew deploys equipment just for shallow ReMi acquisition, it may need to use only a few dozen channels. However, if the ReMi acquisition is to be conducted as part of the active 2D or 3D survey, then of course data from the active deployment can be used which may consist of hundreds or thousands of channels.

Some operators who prefer to have multi-component ReMi data may deploy a small 3C line side by side the active single component 2D/3D line, perhaps slightly offset from it, and if available will use 4.5 Hz geophones instead of the 10 Hz typical on an active crew. However, 4.5 Hz geophones are not essential and 10 Hz geophones can provide excellent ReMi results. The advantage here is to use all or as much as possible of the on-going active operation to provide useful passive data not to add to the crew's work load.

Figure 6: Passive can be acquired using cultural noises our ces. Here Sigma system in use on ReMi survey in Quito, South America.

The same rules of course apply in gathering shallow passive data as those that apply to deeper data. In other words half the maximum offset equals the maximum depth we can register while resolution depends on trace spacing. But if a standard active 2D or 3D survey is being undertaken with 25m to 50m trace interval using conventional arrays of 10 Hz geophones, as an operator gets used to what is achievable in his survey area, there is no reason not just to use passive data (i.e. that recorded while there is no controlled seismic source) by separating the active data from the passive. Some recorders can perform this file separation automatically.

ReMi relies on there being some level of cultural noise, for example nearby motor vehicles, people etc. The ideal recording time depends on many factors and may range from some minutes to hours. As the equipment has had to be deployed for the purpose of active shooting and usually this entails waiting between shots, or some period at the end of the day when the recording system may stay switched on, then acquiring ReMi data usually involves little or no extra crew effort. It is only a matter of the instrument being able to output separated records on the crew itself. However, if the line is long enough - as it often is in conventional 2D/3D recording - then recording channels distant from the controlled source may also be able to make use of the low source energy in their ReMi output.

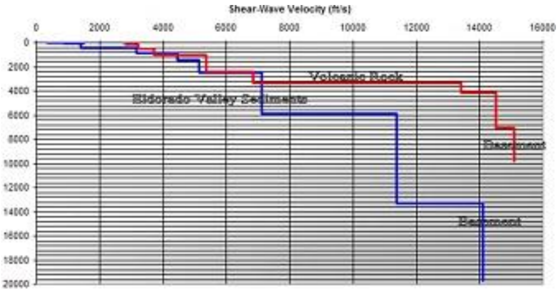

Figure 7: ReMi output of shear wave velocities.

The result of a ReMi survey is a shear wave profile of the near surface from which statics can be picked (Figures: 7, 8, 9 and 10). If required, then compression wave velocities can be provided too simply by using the relevant Vp/Vs approximation conversion factor such as 1.73. Obviously, many companies have alternative methods for deriving near surface statics solutions, for example based on statistical approaches but given that ReMi data is effectively free, it can be a very good test of other statics picking procedures. Most certainly, if there is any difference between the static solutions, some investigation as to the cause of the difference needs to be undertaken. ReMi in this sense acts as low cost but very valuable QC insurance. Although a shallow passive technique, the improvement in data quality which may be possible from the ReMi has been known to help define layers at deep target levels.

Passive techniques - Improving Deep Layer Identification

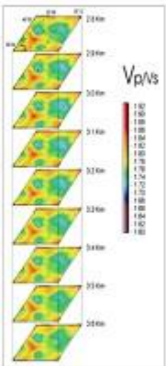

Figure 8: Vp /Vs outputs from passive data.

We now move to looking at how energy naturally generated at depth and acquired on the surface by the standard active seismic recorder (or the same recorder specially deployed for passive acquisition) can improve active data. The process here relies on tomographic imaging techniques using deep natural seismic events which funnel through the target zone from beneath to be recorded on the surface. This tends to work better where natural seismicity is greater. India is fortunate in having many such locations.

As with ReMi, it is possible that the channels deployed by a crew as part of an active survey will suffice for this technique, i.e. geophones laid on the surface. But unlike ReMi, it is better to make use of as many channels as possible, perhaps many hundreds or even thousands from a 3D grid if they are being laid out for active seismic. It may take some hours to record enough energy to get reliable tomographic solutions.

Once again, like ReMi, the benefit to the crew is that this data is free in the sense that is only requires a suitable instrument, which

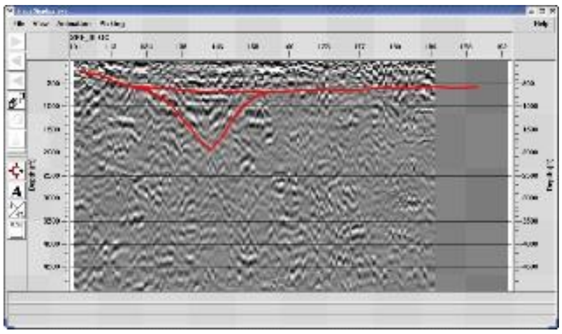
Figure 9: Reflection section generate d from noise records only (high res, 30m spacing, showing basin interpreta tion).

has already been deployed as part of a standard survey, to be left recording between shots or maybe for a little while at the end of the day (or even overnight when manmade noise is at a minimum). Combining this data with active data may well improve the final section, in this case with one application being to determine the thicknesses of deeper layer and their velocities.

As with so much exploration geophysics, there are never guarantees that these passive techniques will work. However, even if today's passive processing is not good enough; data sets recorded with appropriate hardware become available in perpetuity for those who want to study them in different ways at any future time.

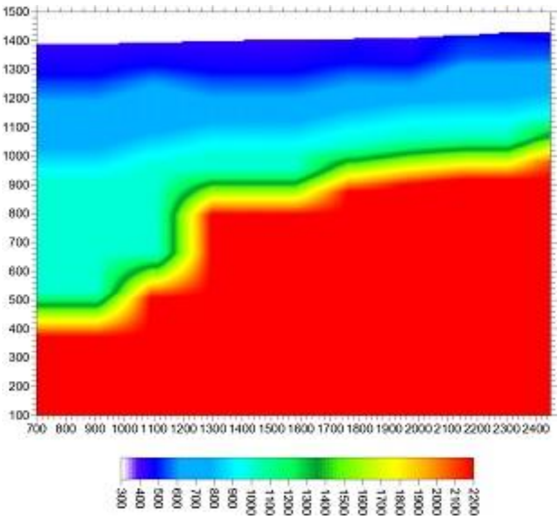

Figure 10: ReMi profile, 1.5 km depth.

Passive techniques - Direct Hydrocarbon Indications

The third and final technique reviewed here is in respect of using passive data as a direct hydrocarbon indicator (DHI). There are various versions of this, some of which are proprietary, and others are far from new but which have become of interest again simply because recording systems and processing techniques have caught up.

The technique reviewed here relies on a hydrocarbon reservoir's ability to respond in a gross sense to some external stimulus. For example, the ocean's tides exerting forces in the reservoir which subsequently help it to become a source of seismic energy itself with some specific characteristics. There is also interest in how a reservoir responds for some minutes after an impulsive shock wave has hit it, perhaps from a seismic dynamite shot.

There appears to be evidence that low frequencies (< 2 Hz) are generated which contain some useful information about the reservoir and its contents. Frequencies below 2 Hz can be acquired using 10 Hz phones, though 4.5 Hz is better still, but often no special sensors at all are needed. Once again the DHI-passive data acquired is essentially free since the active crew will be taking shots and have deployed the system for normal recording. Or, given the flexibility of the recording technology, some special sensors (ultra-quiet, very low frequency response etc.,) could be deployed sparsely amongst the standard active deployment, and passive data sets provided by both equipment. There is really no limit to what "experiments" can be devised as long as the equipment is capable.

Passive techniques -Miscellaneous

There are other examples of passive techniques. Some, including "Seismic Interferometry" and "Ambient Noise Tomography" use cross-correlation between receiver groups in an attempt to create the "Green's Function" that would be observed if a source were located at either of the receiver stations. These techniques try to create shot records for shot-less locations using equipment which has the necessary flexibility.

Other techniques use passive data to locate seismic events (Figure10). For "Hydraulic Fracture Monitoring" (HFM), passive data is searched to locate coherent events (Figure 11 and 12). These events are then mapped to subsurface horizons so that the extent and strength of the fracture process can be evaluated.

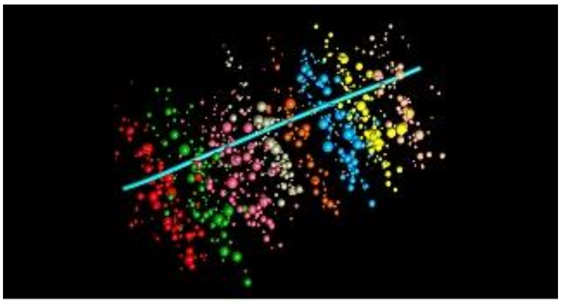

Figure 11: Microseismic event location (Courtesy GeoGiga).

In this technique the seismic events can be very weak. Therefore, sensor placement is more critical than is most others, with many believing only downhole sensors will suffice, while others feel that standard land equipment and sensors will also work well, as long as there is a sufficient density of them. Passive field crews need to balance the number of events recorded versus the cost of capturing those events. Software to process this data is now becoming more widely available, for example such as that from GeoGiga.

Finally, of growing importance and interest, while not strictly a passive technique, is 4D acquisition. This is mentioned here because it can require similar levels of system flexibility as the above-mentioned passive techniques, and in between active 3D time lapse survey, passive data can also be acquired which may in some circumstances add information of value.

Whereas all these techniques differ in how they are conducted and how they may help in our exploration, the common thread is their requirement that one set of recording equipment can cope with them all, as well as handling all types of active acquisition that an operator needs to undertake. It is thus important to consider technologies which can "do it all".

Recorder Considerations

One issue fuelling the growth of passive recording is that hardware no longer is tied to using telemetry cables. Freed from this constraint, active crews can be much more productive and passive data can either acquired as a subset of the active crew, or smaller passive crews can be set up to operate on their own, or indeed work side by side an existing cabled system.

From the hardware perspective, passive operations make far more demands on a seismic system than active recording. This has been covered already in the literature (Heath R G., First Break Vol 29) but simultaneous use of a single instrument for passive and active were not therein covered in detail. However, it is the case that if a system can cope with all the various requirements of passive recording, it will easily cope with any active survey. Therefore, we need only consider what is needed by a cableless instrument to be able to take on the widest number of passive roles as this presents the greatest challenge to any instrumentation.

Whereas active seismic acquisition, whether with telemetry cables or the latest cableless hardware, always benefits from communication between the central system and all deployed ground channels, some passive recording may not so require full time or real time communication. If a single system is going to be chosen to take on all active and passive jobs, then most certainly at least some level of communication capability is essential.

Wireless communications are always a compromise between three issues: data rate, wireless range and deployment effort. Any one of these cannot be improved without another suffering. Both range and data rate can be increased if the user if willing to deploy better antenna perhaps in much elevated positions. But this is not practical for many channels or in tough locations. The situation is made worse by the need in most cases to use the only licence-free band of 2.4 GHz which performs badly in humid or forest environments due to high degrees of radio energy absorption by water molecules in the atmosphere or foliage. Thus, how well such systems work may be determined even by something as simple as local weather conditions. Claims are sometimes made by manufacturers that their 2.4GHz technology is able to achieve connectivity at high data rates and suitable ranges for passive in areas of dense vegetation and independent of weather but the laws of physics make this most unlikely. Indeed, simple test instrumentation easily demonstrates the realities.

However, in the Indian context this presents special problems.

Figure 12: Passive acquisition with realtime Sigma cable less system, China.

The compromise for active and passive operations is to have simple deployment and not attempt communication bandwidths which are too high. Technology today allows mesh network radio (MRN) based equipment to be used simply even in thick jungle environments and communicate all the necessary QC, security, noise and instrument information. Almost all major passive operators have chosen the same single system because of this unique ability.

Most new recorders have 32 bit analog to digital conversion. This does not mean they have eight more bits of useful data than 24 bit convertors but they tend to have very slightly better specifications which may be of special advantage to passive recording. They also benefit from some other useful features such as lower power usage, bit utilisation and better recovery from overscale. It is unlikely that any system in future will offer anything less than 32 bit, and if planning to use the same recorder for joint active/passive, it is recommended that nothing less than 32 bit is accepted.

A passive system must also be capable of accepting a wide range of sensors and have the facility to change its low-cut filter response. Many instruments do not offer a low-cut below 2 or 3 Hz and it is clear that this is insufficient for almost all passive work. There are, however, instruments which permit the user to choose low-cut of 2Hz, 0.1 Hz and "off", and the selection of which can be performed over the same MRN communication system.

Apart from standard geophones, the same system must also accommodate powered (active) sensors, such as those from Guralp, and also 3C sensors. (Figure 13). Energy usage on cableless crews must be monitorable (for example by use of the MRN) but it must also be minimised. Therefore, the ability to remotely switch on/off power to external sensors as well as the ground unit itself is very useful. Because most passive data requires very low noise specification on sensors, MEMS is for the most part inappropriate for passive 1C or 3C recording.

Figure 13: Testing of different passive and powered sensors, data transferred by WiFi in this case. Coutesy Spectrase is and iSeis Cos.

Fortunately, there is much in the literature (for example, Hauer *et al*, 2008) to demonstrate that in most active recording, modern analog high specification 3C phones outperform MEMS in many ways, especially in areas of high rainfall. This appears to be because a rain drop hitting MEMS sensor has a similar mass to that of the suspended MEMS device. In other words, MEMS data can be even noisier in areas of high rainfall, which is a special disadvantage for passive recording.

Security of data and equipment is important for active recording crews but even more so for passive operations as equipment may be deployed for longer or in more remote places. There are various ways to avoid or reduce equipment theft with some equipment apparently having far better performance in these essentials than others. The ability remotely to monitor noise around deployed sensors, for data quality and security reasons, is essential.

Some passive surveys greatly benefit from real time transmission of all data, sometimes over very large areas (perhaps up to 1,000 sq.km) and this requires the recording system to be able to work with long range directional 2.4 GHz antenna and the right communication protocols. This option may not always be required but it is very useful for both active and passive recording when it is available, though it depends on the amount of effort the operator is willing to put into deploying the necessary equipment.

Due to the difficulties posed when trying to operate high bandwidth 2.4 GHz communication links, it is also most useful to have a variety of data harvesting techniques when it comes to passive acquisition, and especially offer some which are not dependent in any way on 2.4 GHz connectivity. Passive data may be recorded over long time periods but it is useful to be able to gets copies of it during the recording phase, leaving the ground unit in position to go on recording. This requires the ground boxes to have sufficient memory capacity but also that direct memory copies though USB-like or wired Ethernet connections can be made to it.

In conclusion, a modern passive recorder requires levels of flexibility never yet found in any cabled system and this explains why cableless technology is the choice for those undertaking passive. However, many cableless recorders are designed only primarily for active operations and so do not have the flexibility necessary for much passive.

Therefore, the ideal passive recorder needs a guarantee of at least a minimal level of communications in all environments but options for very long range and/or high data rate links where necessary. Where real time transmission is not used, the recorder needs high levels of internal memory and the ability to copy from it by not just by wireless but also by other data transfer methods without interrupting acquisition. Ground units must be capable of connection to simple single component geophones, as well as 3C, active and very low frequency/low noise phones depending on the nature of the active, passive or joint recording.

Fortunately, today's technology does allow systems of such configurability to exist, and for that we must be thankful and this is what is making passive recording available to many more. Essentially this is one more area where new cableless recording technology is advancing acquisition geophysics.

Summary

Geophysical field projects are expensive in terms of both time and resources. Once the geophones and seismograph have been deployed in the field, recording as much data as possible is important. This includes not only convention shot records but perhaps also ReMi / MASW during the day, and deeper tomography data at night. There are many options, and the modern geophysicist should consider them all.

And for this geophysicist who wants to have available the maximum amount of information to improve his final sections and interpretations, then it no longer makes sense necessarily to think in terms single component, 3C, active or passive projects as being distinct and separate acquisition phases or recorder requirements. There are already many reasons to undertake "combination recording" and the number is certainly increasing.

If there is to be on-going change in the landscape of geophysical innovations, appropriate recording techniques and technology must be used in imaginative and flexible ways to provide multiple types of data sets which can be processed with today's techniques in the present, and future techniques tomorrow.

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