

A simplified tap test method for multicomponent seismic surveys

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ABSTRACT

One of the most tedious and time-consuming aspects of 3-C processing is determining exactly how the data were acquired and recorded. To process a 3-C dataset, the processor must identify and individually manipulate data from each 3-C geophone axis. In order to do this properly, the processor must have full knowledge of which geophone element corresponds to each channel of a shot gather. The direction of each element with respect to the survey stations must be known. The polarity of each element must also be known, so that the processed section has unambiguous polarity. For some processing operations, such as shear-wave splitting analysis, it is vital that the direction and polarity of both horizontal elements is well understood.

The present state of the art for 3-C surveys is improving, yet a large percentage of 3-C surveys are shipped to processors with inadequate information on geophone orientation, element orientation (within the geophone), element-to-channel mapping, and element polarity. In many cases, the processor is forced to fill-in missing information with educated guesses. This has undoubtedly resulted in incorrectly processed data, and ultimately, a loss of money invested in acquiring multicomponent data. The development of standards for tap testing and recording could largely alleviate these concerns.

INTRODUCTION

A comparison of common 3-C geophones shows that there is little commonality between the case markings, geophone element orientation, and element polarity for different brands and models of 3-C geophones (Lawton, 1991). In practical terms, each set of geophones must be assumed to be physically different. Recording crews should be familiar with the geophones in use, and they should pass on this knowledge to the client (and ultimately, the processor). However, geophone information rarely accompanies geophones, and is often not communicated to the processor.

A common source of uncertainty in the processing stage is the correlation of geophone elements to recording channels. Most land 3-C data is recorded on instruments and cables that were designed for 1-C recording. Most 3-C geophones have their elements wired to three mechanically identical connectors, rather than use six-pin connectors¹, which reduce the risk of incorrect geophone cabling. The field crew has to exercise a great deal of care while hooking-up geophones, so that components appear at the recorder in a consistent and well-understood fashion. In most cases, field crews (including those comprised of our own researchers) succeed

¹ A custom 3-C recording cable based on six-pin connectors was designed and tested by researchers at CREWES. First shown at the 2000 CREWES Sponsors meeting, this cable is fast to deploy, and avoids connection errors. Contact crewesinfo@crewes.org for more information.

in wiring the geophones consistently, however, they are uncertain about which element is connected to which channel. Most crews are even less sure about geophone polarity.

An additional source of uncertainty is the orientation of the geophones as planted in the field. For most rectilinear surveys, all geophones are planted with the same orientation, and the observer simply needs to draw a diagram that includes directional markings on the geophone case and a reference direction (typically North). For crooked line surveys, there are two common practices, (1) Orient all geophones relative to the line-direction at each individual station (i.e., turn the geophone's H1 arrow to point to the next receiver station), or (2) orient all geophones to a common reference direction (i.e., turn the H1 arrow to point directly west). Unfortunately, a large percentage of surveys are sent to the processor without diagrams or field notes that explain how the geophones were oriented.

In fact, problems related to 3-C processing are almost all grounded in poor documentation. This is not surprising, since 3-C recording remains an exception rather than the rule, and only a select few are knowledgeable about the unique challenges of 3-C acquisition.

TAP TESTS

Field crews typically rely on tap tests to help them understand how 3-C geophone elements appear at the recorder. There is no industry-wide convention for a 3-C tap test procedure. Most tap testing consists of recording a series of taps on a single geophone in three directions: (1) downward, (2) in line with the primary arrow marked on the top of the geophone (sometimes labelled H1 or X), and (3) in line with a secondary arrow marked on the top of the geophone (sometimes labelled H2 or Y). Tap tests are usually performed and analyzed in the field. Varying amounts of information regarding tap tests are passed-along to the client. This ranges from absolutely nothing, to a fully detailed documentation accompanied by digital recordings of all relevant channels. In most cases, the processor must rely on the field-interpretation of the tap tests, because of missing or inadequate data and documentation.

Conventional tap test procedures are of little use without documentation. For example, if a tap test is performed, recorded to tape, and documented in the observers notes as, "tap tests were performed by tapping in the direction of the arrows on the geophone case", the processor cannot fully understand the layout and polarity of the recording system. Which way did the geophone arrows point (is the H2 arrow 90 clockwise or anti-clockwise to the H1 arrow)? Which way was the geophone oriented when planted on the recording line? Which arrow was tapped first? Without this information, the processor will probably ignore the tap test, and make an educated guess based on painstaking analysis of prestack data.

Coordinate naming convention

Before proceeding we shall define a coordinate naming convention. When referring to X , Y , and Z axes at geophone stations, the Z -axis increases in the downward direction, the X -axis increases in the direction of increasing receiver station number along a receiver line (or line segment), and the Y -axis increases in the direction 90° clockwise from X when viewed from above. When standing at a receiver station looking down a receiver line (towards increasing station numbers), the X -axis increases in the forward direction, and the Y -axis increases to the right. Though it may be tempting to use the terms *in-line* and *cross-line* to describe the X and Y directions, these should be avoided because they might have conflicting definitions. The term *cross-line* is most easily confused in 3-D surveys, since some surveys have receiver lines whose receiver-line number increases in the positive Y direction, while others increase in the negative Y direction. Those familiar with polarity standards should note that the author is defining the axes based on receivers, not sources. A source-referenced definition of the X , Y , and Z -axes is presented in the vibratory source polarity convention (Landrum et al, 1994).

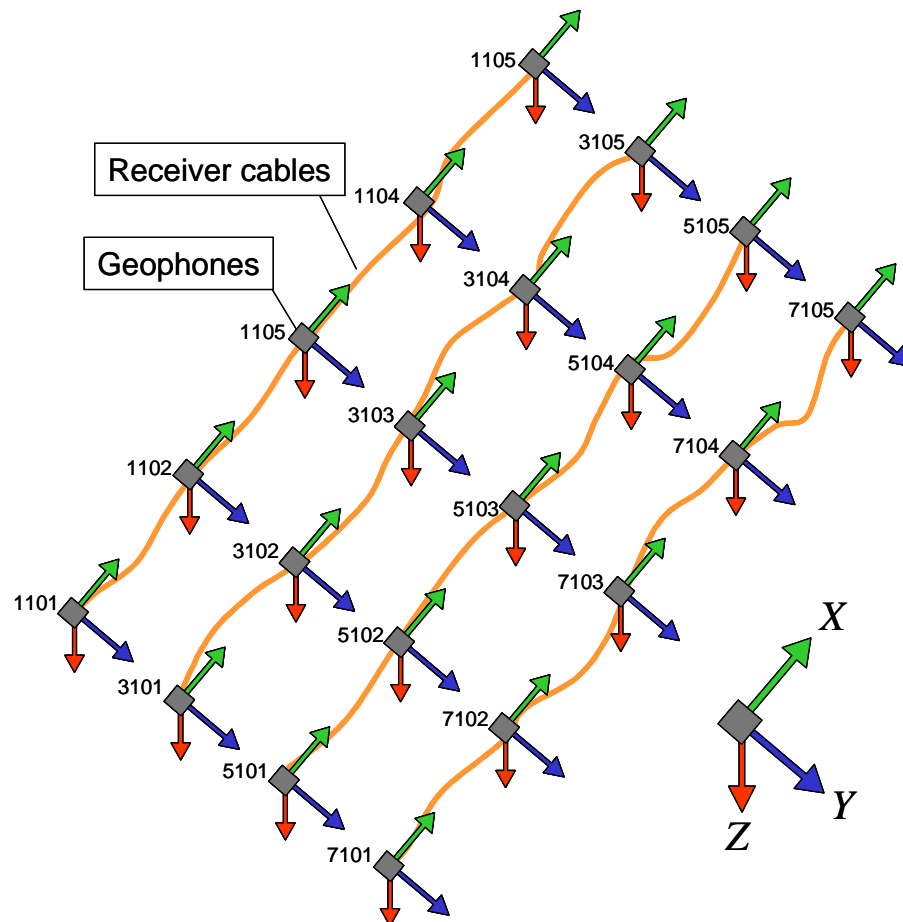


FIG. 1. Acquisition coordinate system based on receiver line direction. The X coordinate points along receiver lines in the direction of increasing receiver station numbers. The Y coordinate is 90° to the right of X when viewed from above. The Z coordinate is downward (from Gaiser, 1999).

TOWARD AN IMPROVED TAP TEST PROCEDURE

Tap testing is usually a two-person job. The observer operates the recorder: manually triggering the instruments and making notes. The individual performing the taps (the tapper) is typically another member of the field crew in radio contact with the observer. The tapper needs to perform a series of taps (at least one in each primary direction) and do so in concert with the observer's instructions. Getting the tapper to tap the geophone in the correct directions has proven a difficult task, because the conversation usually takes place over a radio where gestures cannot be used to help explain the instructions. Having the tapper memorize the correct tapping instructions ahead of time is also problematic. We have struggled to devise a script of instructions that the observer might read to the tapper. These instructions need to be simple, short, unambiguous, and foolproof. In testing possible scripts, we've been disappointed to find that verbal instructions are prone to misinterpretation (particularly by researchers who specialize in multicomponent acquisition!). This is usually because the instructions depend on abstractions that are difficult to grasp, especially while working in difficult outdoor conditions. The best way to ensure an accurate set of tap tests is to send the tapper to the tap test station with a picture-based instruction sheet. A sample tap test procedure is shown in Appendix A.



FIG. 2. Two people must coordinate their efforts to successfully record a tap test. The tapper (shown above) goes to a tap test station and stands on the receiver line facing the next bigger geophone station number. Once oriented, the tapper taps the geophone, and calls-in the tap direction and geophone station number. The recorder manually triggers the instruments and makes note of the tap test details.

Tap test trials

To gain a better understanding of geophone responses to tap tests, 120 tap-tests were performed on various 3-C geophone models and makes. The geophones were planted on the surface of grass-covered soil, with great care taken to ensure that the geophones were firmly planted and levelled.

Geophones were tapped in five directions: Z, X, -X, Y and -Y. Taps in the negative X and Y directions were included to help us note any irregularities in our tapping and data manipulation. In many instances, tap tests were obscured by background wind noise and additional taps in opposite horizontal directions helped us to interpret the tests. We now propose that *all* tap tests include taps in the -X and -Y directions.

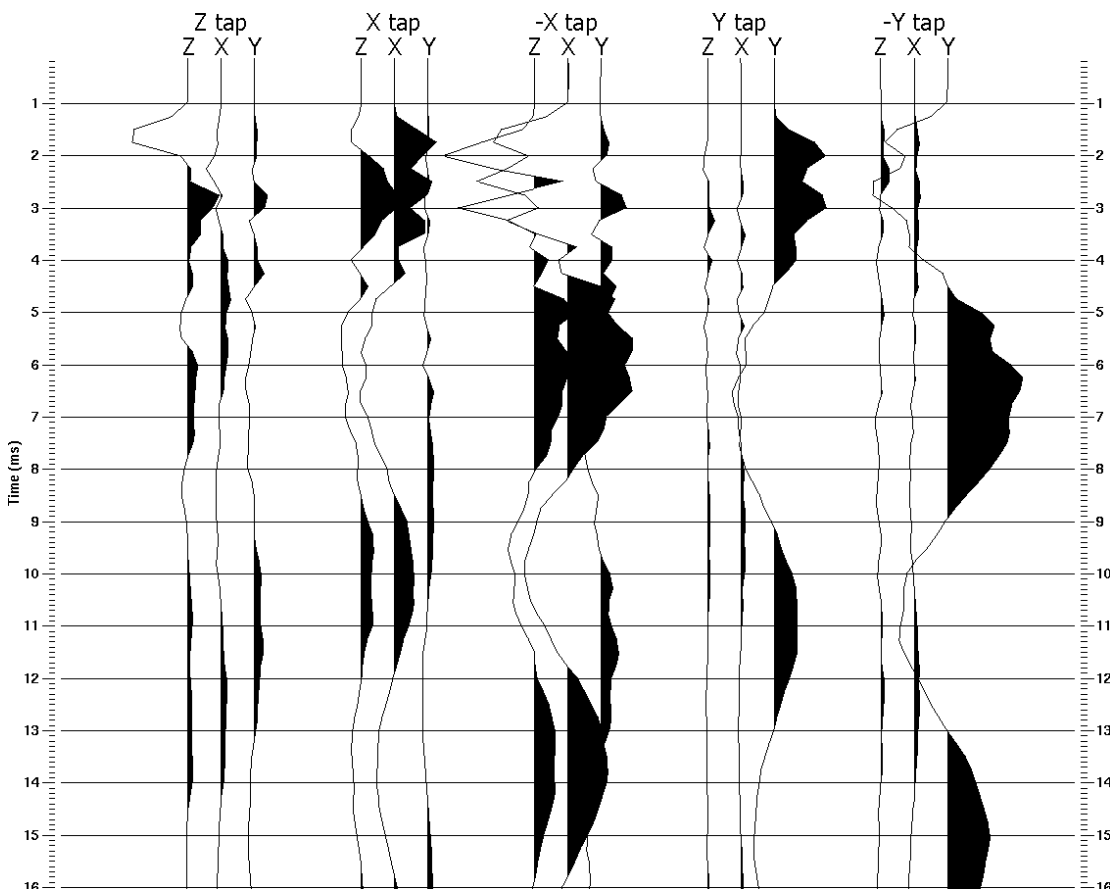


FIG. 3. A series of tap tests on a Litton 3-C geophone. From left to right, the first group of traces was recorded as the tapper tapped the top of the geophone. The second and third sets were recorded as the tapper tapped the side of the geophone in the X and -X directions. The fourth and fifth sets were generated when the tapper tapped in the Y and -Y directions. Data are plotted with a constant scale factor for all traces.

Figure 3 shows a tap test result. Traces are grouped in sets of three, in the sequence (Z, X, -X, Y, -Y). Note that, (1) tap energy is often picked-up by orthogonal elements, and (2) the geophone seems more sensitive to horizontal taps than vertical taps. The tap test in Figure 4 illustrates a common problem, where a vertical tap generates a large response on the horizontal elements, and only a small response on the vertical element. This is probably a result of the mechanical planting of the geophone. When a geophone spike is pressed into the ground, it compresses the soil beneath it, forming a rigid barrier to downward motion. The soil around the sides of a geophone spike does not undergo the same compressive force, and the geophone is therefore more prone to horizontal motion when acted upon by a tap.

What produces the best tap?

The tap test field experiments were performed with different objects, 1) the eraser on the end of a pencil, 2) the tip of the pencil (the pencil “lead”), and 3) the tapper’s index finger. The recorder was manually triggered and recorded 512 ms at a 0.25 ms sample rate. Tapping was performed at a rate of about four taps per second. This is an ideal rate because it allows several taps to be recorded on a single trace, and there is enough time between taps that recorded events do not overlap. To simplify the display of tap tests, we aligned all tap events to a common start time.

Figure 4 shows that there is little to distinguish a vertical tap from a horizontal tap when the tapping was done with a finger. This could be due to finger joints, which flex to produce sideways-motion at the moment that the fingertip strikes the side of a geophone. Tapping with a pencil-eraser is better, but a vertical tap still results in the horizontal components having a larger response than the vertical component (Figure 4). The best result appears to be from tap tests using the tip of a pencil. This tap produces a distinctive high amplitude spike for a vertical tap test.

How best to record a tap test

The dominant frequency of the tap test records is between 150 and 200 Hz. Since this frequency is higher than normally recorded on reflection data, the sample rate should be increased. The optimum sample rate is 0.25 ms, and should be at least 1.0 ms. Large sample intervals make tap tests very difficult to interpret (Figure 5).

It is important to plot tap test data at a suitable time scale. It is easiest to interpret tap tests when plotted at 50 cm/s (20 in/s). If data are plotted with a compressed time scale, it is easy to misinterpret the polarity of a tap test. We have found that some field recorder plot routines do a poor job of down-sampling traces for plotting, resulting in misleading plots and incorrect tap test analyses. It is therefore important to record tap test data on tape, rather than depend on monitors.

We suggest a five-part tap test with one tap in each of the Z, X, -X, Y and -Y directions. First, have the tapper stand facing the tap-test geophone, and increasing station numbers on a receiver line. Second, relay the instructions in Appendix A to the tapper via radio.

One astonishing observation of 3-C field data is that 5-10% of commonly used 3-C geophones are miswired (Cary, 2001). Since there is generally good quality control on the planting and cabling of 3-C geophones, these errors must be due to problems with the internal wiring of the geophones. Regardless of the cause, it is advisable to perform tap tests on more than one geophone (three is ideal) just in case any one geophone is miswired and does not represent all geophones on the spread.

What else do we need?

The key to a useful set of tap tests is adequate documentation about tap directions. The proposed procedure makes no reference to the geophone orientation. Since tap tests are performed relative to the survey's station numbers, we only need to ensure that geophones are oriented consistently throughout the spread.

Ultimately, the purpose of a tap test is to 1) tell the processor how the geophone elements were oriented and polarized relative to a survey-based coordinate system, and 2) relate geophone orientation to recording channel number. If tap tests are performed relative to a geophone-based coordinate system (such as tapping in the direction of arrows on the case), we add an extra layer of complexity. Now, in addition to basic tap test information, we also need to know the relationship between the geophone's coordinate system and the survey's coordinate system. Geophone arrows are notoriously hard to read, and poorly labelled. The proposed tap test procedure eliminates the need for diagrams showing the geophone orientation and arrow direction, and also eliminates the need to distinguish (or even see) the arrows on the top of a geophone.

INTERPRETATION OF TAP TESTS

Tap tests are commonly interpreted by determining which channel is associated with the vertical component, then determining which channels are associated with the *X* and *Y* components. The *Z* component often contains the least amount of signal, and therefore, one of the horizontal elements is misinterpreted as being the vertical component. The preferred method of interpreting a tap test is to determine the *X* and *Y* components, and thus define the *Z* component by process of elimination. Also, the *Z* component should have a higher frequency spike when tapped in the *Z* direction when compared to the *X* and *Y* components.

Polarity of the tap test needs to be interpreted relative to the polarity standard required by the client. For 3-C recording, we advocate the polarity standard in which an impulse on a geophone case in the positive *X*, *Y*, or *Z* direction results in a positive kick on the *X*, *Y* and *Z* channels.

CONCLUSIONS

We have made a case for a standardized 3-C tap test procedure that is independent of geophone case markings or geophone orientation. Instead, it relies on the survey geometry (receiver-line direction) as the basis of orientation. Since most problems associated with 3-C recording are related to inadequate documentation, our tap test procedure should help, since it is less dependant on field-generated documentation than conventional tap test methods.

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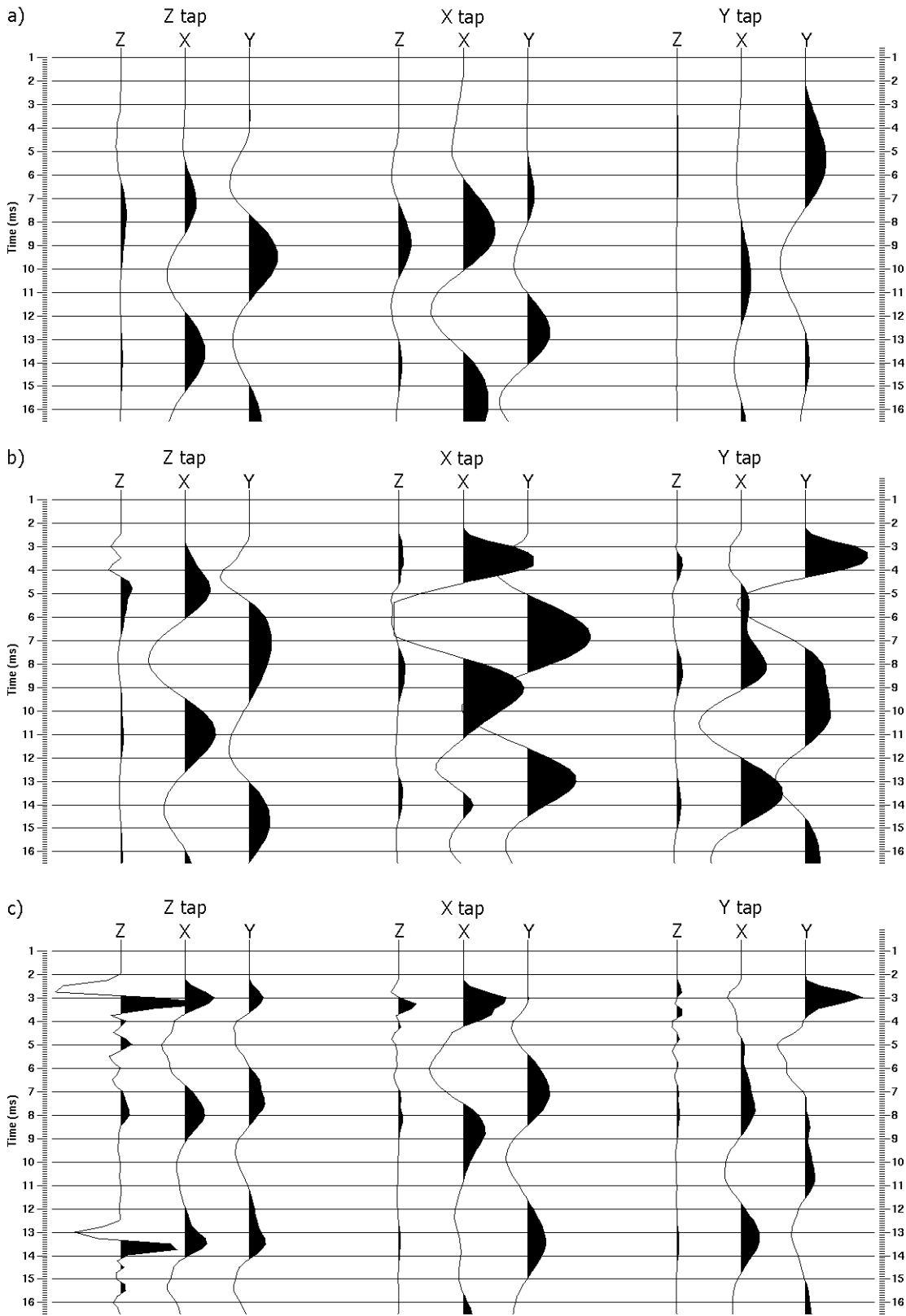


FIG. 4. Output traces from a three-component geophone when tapped with different objects: (a) finger tip, (b) eraser on the end of a pencil, (c) sharpened tip of a pencil.

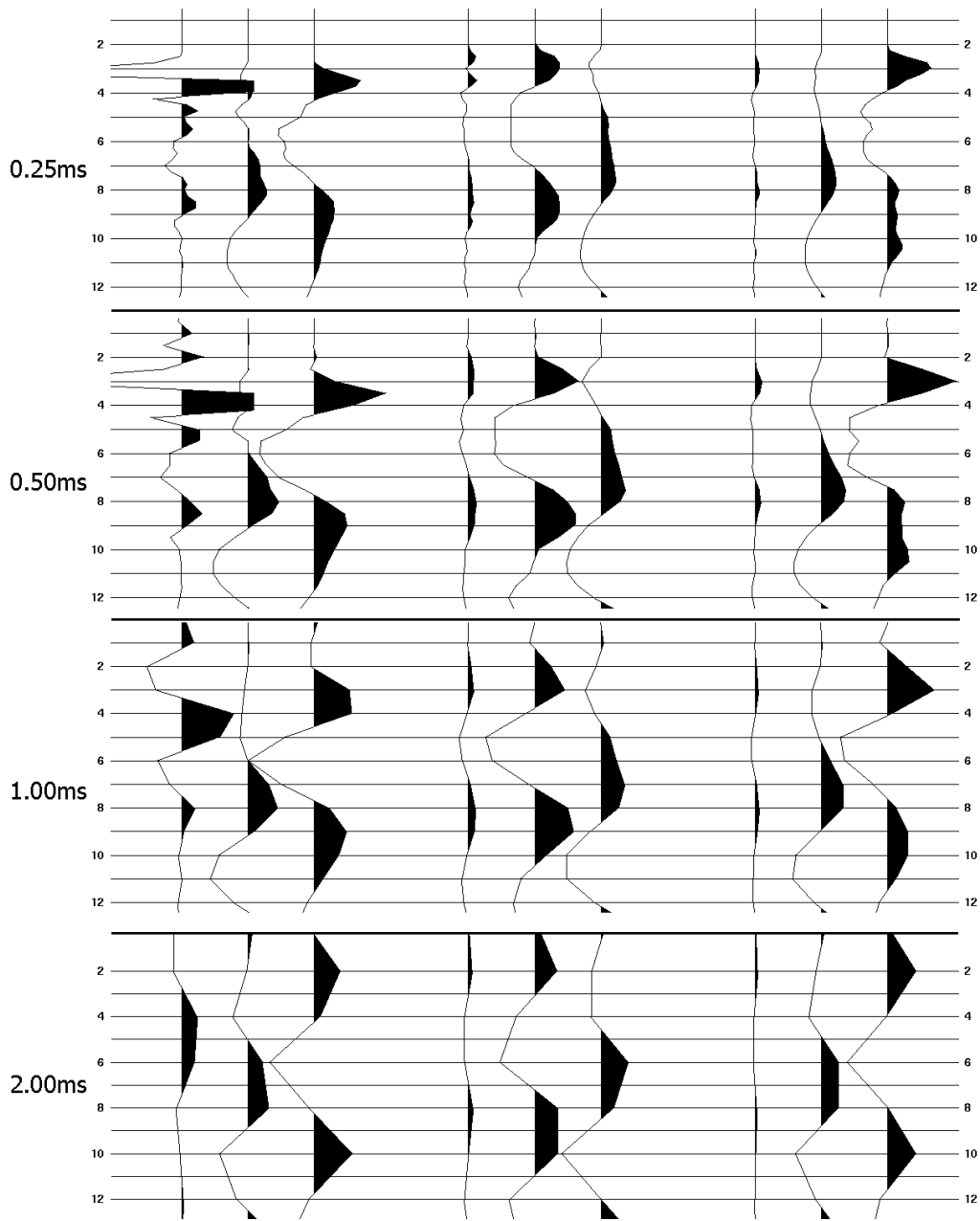


FIG. 5. Recording tap tests with course sample rates makes them difficult to interpret. Each group of three traces is the vertical, in-line, and cross-line component from a 3-C geophone. The group of three of traces on the left is from a vertical tap. The centre traces are from an in-line tap, and the right three traces are from a cross-line tap.

APPENDIX A
PROPOSED CREWES 3-C GEOPHONE TAP TEST PROCEDURE

Instructions for the recorder

- Set the instruments to: 0.5ms sample interval (0.25ms if your system is able), 1000ms record length (minimum), Dynamite mode, 1 stack, manual (keyboard) trigger
- You should perform the tap test on three different 3-C geophones stations. Select tap test stations that are spread-out along the line (or 3-D patch). Do not choose stations that are at the start or end of receiver lines.
- Record ALL THREE components of the tap test geophone to tape.
- For each tap test record, make note of the file number, the tap test direction (Down, Near, Far, Left, Right), and the tap test station number.
- Make sure that the tape with tap tests is shipped to the client along with the production data.
- When you send someone out to tap a geophone, make sure he takes along a copy of the **Tap test reference card**.
- The recorder should ask for tap tests by number. When the tapper is tapping, he should (with his other hand) call-in the tap direction and station number over the radio. This helps avoid the case where the tapper is tapping in one direction, but the recorder writes-down a different direction in the observer's notes. Here's a sample radio conversation:

Recorder to tapper: *Go out to the geophone at station 1121, and get set up according to the tap test reference card.*

Tapper: *Ok, I'm ready at 1121.*

Recorder: *You should standing with the geophone at 1121 directly in front of you, facing toward the geophone at 1122.*

Tapper: *That's how I'm standing.*

Recorder: *Do tap test **one**. Call-in your tap direction and station when you've started tapping.*

Tapper: *tapping **down** at station 1121*

[Recorder triggers instruments manually, writes down "tap test down at station 1121" beside the file number in observers notes.]

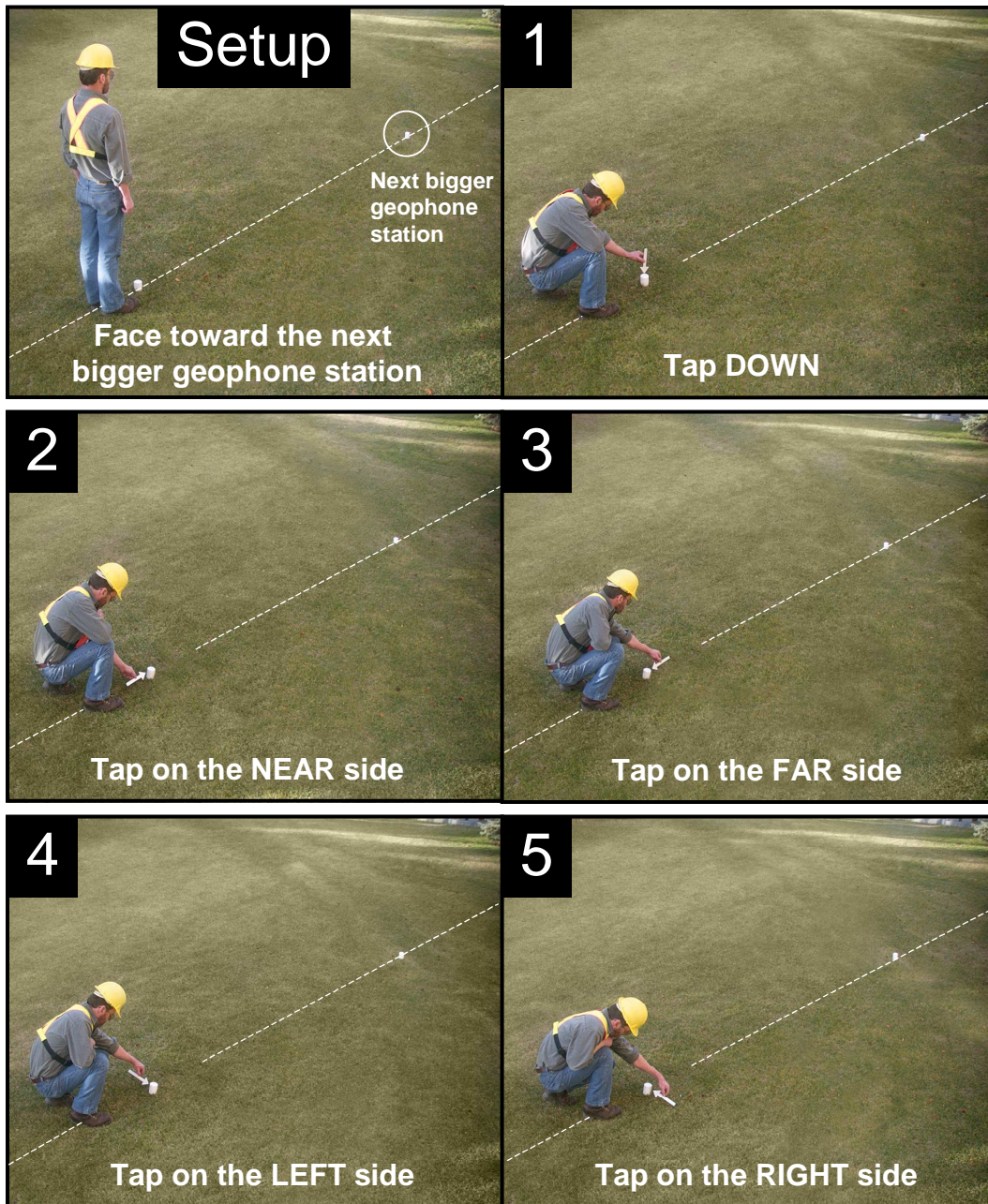
Recorder: *Ok. Now do tap test **two**. Call-in your tap direction and station when you've started tapping.*

Tapper: *Tapping on **near** side of geophone at 1121*

[Recorder triggers instruments manually, writes down "tap test on the near side of the geophone at station 1121" beside the file number in observers notes.]

[Repeat for the other tap tests 3-5].

Tap Test Reference Card



Notes to the tapper:

- When you tap, use the tip of a pencil (the end with the lead). Do not use your fingertip (it's too soft) or anything metallic or magnetic.
- When asked to tap, tap several times until asked to stop. A rate of 4 taps per second is ideal.
- Tap quickly and very gently.