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DESIGN AND CONSTRUCTION OF A PROTOTYPE CANNONGUN AS A SEISMIC SOURCE

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ABSTRACT

A cannongun seismic energy source has been successfully designed and constructed for use in shallow and medium range seismic surveys. The source which consists of four detachable subunits has a total mass of 400kg. It is an explosive based in-hole impactor, which can be moved around on a 2-tyre carriage. The maximum charge size it can fire without bouncing was found to be 1000 grains (200KJ) of black powder. When tested, the source was found to be repeatable, hence signals generated by it are stackable. Again, the first breaks of the seismic signals emanating from the cannongun shots were clearly evident on the record sections at offsets of about 200m; and depths of up to 90m have been successfully delineated during test runs. Though the source is invasive, the destruction to the environment usually caused by explosive shots is almost non-existent in this source-system. It is equally sound proof, so it can be operated in built-up areas including cities without causing any significant problems to structures or noise pollution. The total cost of expenditure for producing the cannogun is highly affordable and the materials are locally available.

KEYWORDS: Cannongun, explosive, seismic, source

INTRODUCTION

Engineering and environmental studies may involve seismic investigation of structures located at depths beyond the shallow subsurface (i.e., >30m). It may also involve the investigation of peculiar geologic sites like landfills which typically attenuate seismic waves much more quickly than do natural geologic materials (Steeples 2000). In such geologic situations, low energy sources like the sledgehammer may fail to yield useful results. As such, a more powerful seismic energy source would be required. This higher energy requirement necessitated the adaptation of the cannongun as a seismic energy source.

This paper describes the design and adaptation of a prototype cannongun as a seismic energy source. The cannongun is an explosive based impactor, moved around on a 2-tyre carriage and is capable of firing a maximum of 200kJ of black powder without bouncing. The 400kg source is designed to use its weight as the basis for achieving improved transmission of useful source energy, without drastically reducing the mobility of the source. Experimental tests were conducted for the evaluation of the new cannongun source. The three parameters used for the evaluation of the source are: (1) repeatability, (2) energy range, and (3) maximum charge size.

DESIGN AND ADAPTATION

The cannongun source is designed primarily for use in engineering and environmental investigation of structures beyond the shallow subsurface. However, the source may be used for a wide range of seismic studies involving moderate explosive charges. The cannongun is technically adapted to among other requirements: (1) be repeatable, to aid signal enhancement; (2) contain high frequency,seismic waves (i.e.,> 80Hz; Sheriff, 1991) necessary in particular for shallow seismic reflection surveys and in general for the resolution of small structures associated with the shallow subsurface; and (3) be capable of delivering enough energy to reach the envisaged subsurface targets and bring back vital information to the jugs at the surface.

The cannongun source has four subassemblies namely: (i) barrel (ii) dome (iii) shock absorber and (iv) carriage. A schematic cross-section of the prototype cannongun source with part numbers given in parenthesis is shown in Figure 1, while Figure 2 is a live picture of the cannongun taken during site preparation for evaluation tests at the Unical test site with some students of the Geophysics Unit, Department of Physics, University of Calabar, Nigeria.

Barrel

The cannongun barrel is made up of the chamber (part 16), segmented pipes (part 14), barrel-nipple-end (part 11), and the barrel hanger (part 13). The chamber is machined from a stainless steel caterpillar shaft. The shaft was annealed to make it machinable. The chamber has an external diameter of 5.7cm and an internal diameter of 3.9cm, effective length of 20cm, depth of 18.5cm, and an overall length of 23cm. The extra 3cm is for the end bolt. One end of the chamber is open while the other end is closed. The external diameter of the closed end is reduced and threaded so that the nut-end of any of the pipe segments can be fitted into it. The first 0.5cm of the thread for the nut end is removed so that the mating parts of the pipe compress each other. There are three segments of the pipe which give a total length of 68cm. The first pipe segment is 32cm long, the second 24cm, and the third 12cm. The pipe is segmented so that appropriate barrel length can be used for specific sites. The open end of the barrel-nipple-end has exactly the same dimensions with the nut-end of the pipe segments which makes mating possible. The closed end of the barrel-nipple-end has end thickness of 2cm. The barrel-hanger is an 18cm diameter plate with thickness of 4cm. A hole is opened at the centre of the plate and is threaded to fit like a nut to the threaded external surface of the barrel-nipple-end. Another 1cm thick plate, having a diameter of 10cm is also made inform of a nut (part 21) to fit the external side of the barrel-nipple-end. This smaller plate (nut) is used to lock the barrel-hanger into position.

Dome

The cannongun dome has subsidiary parts which include the dome-casing (part 5), dome-support-plate (part 20), and dome-hanger (part 6). The dome-casing is a steel cylinder of external diameter 41cm and internal diameter 34cm. The height of the cylinder is 71cm. Two 1.2cm thick internal plates (parts 4 and 22), each with a central hole

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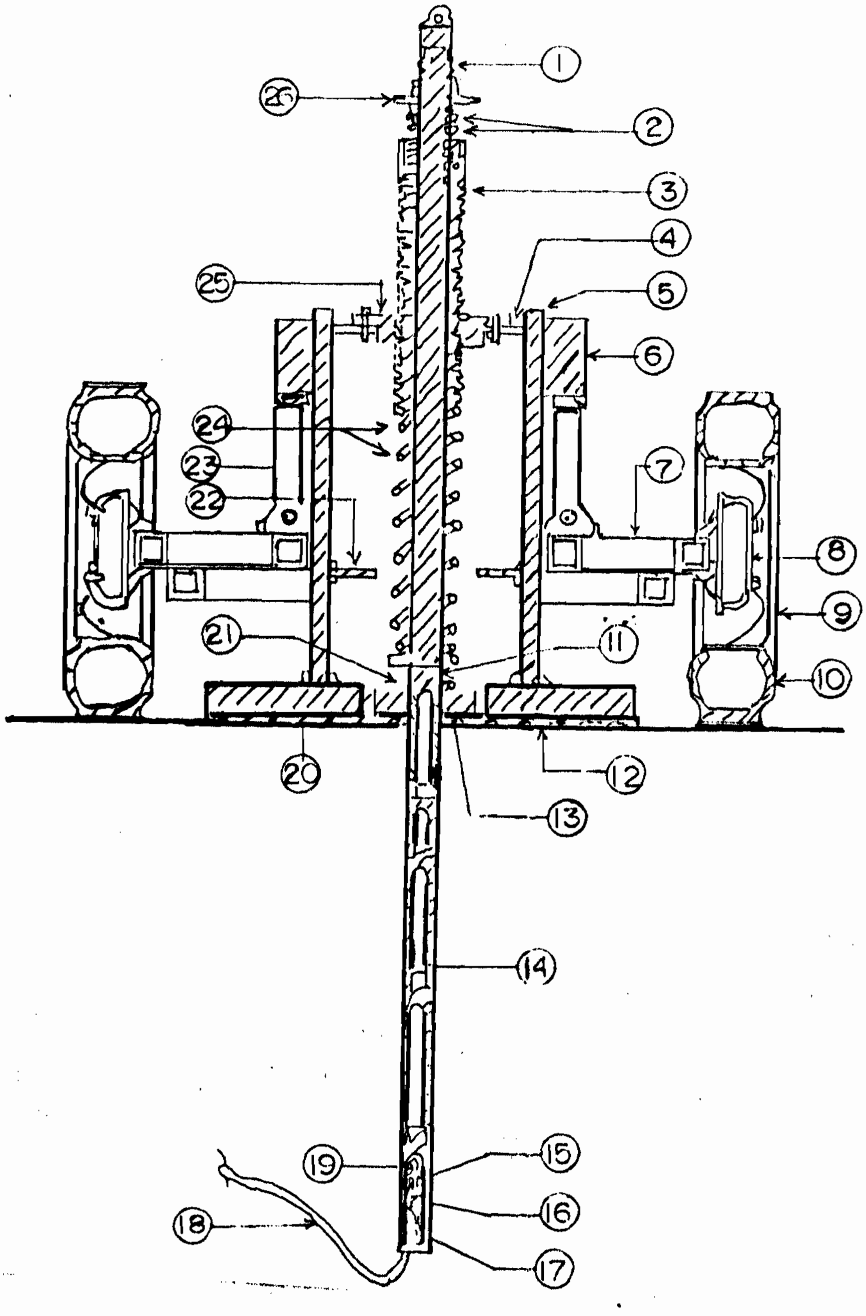
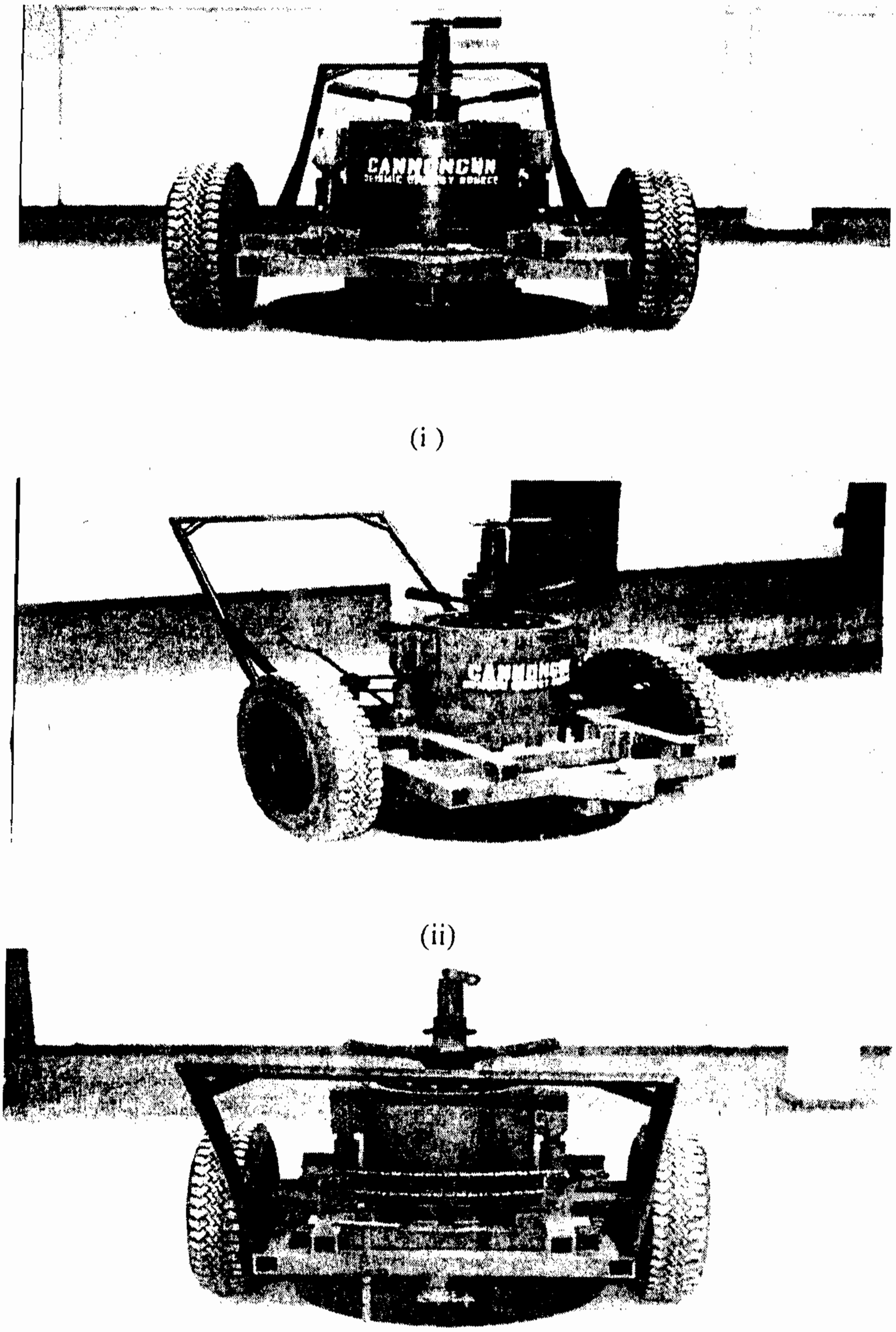


Fig. 1 : Schematic Model of the Cannongun Source. Parts are drawn to scale except that the very tiny parts have been exaggerated for better illustration. Cicled numbers denote the following parts: (1) shock central rod, (2) auxiliary springs, (3) shock pipe, (4) upper dome internal plate, (5) dome casing, (6) dome hanger (7) carriage support frame, (8) hub, (9) rim, (10) tyre, (11) barrel nipple end,(12) anti-vent foam, (13) barrel hanger, (14) barrels (15) black powder, (16) chamber, (17) laterite, (18) cable from blaster to power pack, (19) blaster, (20) dome support plate, (21) barrel hanger lock, (22) lower dome internal plate, (23) jack, (24) main spring, (25) flange end of the shock hanger, and (26) central rod stopper (nut).

diameter of 18cm are welded at heights of 20cm and 67cm from the base of the dome-casing. The base of the dome-casing is welded rigidly to the dome-support-plate, while the top internal plate is fitted to the upper flange-end of the shock-hanger with ten bolts. The bolts fit into nuts which are welded rigidly to the under side of the holes made at the top internal plate of the dome. The lower internal plate serves to prevent dust and sand resulting from explosion, from clogging the thread of the shock-hanger. The dome-support-plate together with the dome-casing and shock absorber, provides the bulk of the inertial mass required to keep the explosive energy to the ground and reduce recoil to negligible proportion.



(i)

(ii)

(iii)

Fig. 2: Different views of the cannongun source. The pictures show: (i) front view, (ii) side view, and (iii) back view, of the cannongun source.

Shock absorber

The shock absorber system consists of the flange end of the shock hanger (part 25), threaded shock pipe (part 3), main spring (part 24), central rod (part 1), central rod end plate (lower end of part 1), central rod stopper (part 26) and two stainless steel auxiliary springs (part 2). The flange hangs the entire shock absorber system on the top internal plate of the dome. The threaded pipe hangs with its threads on the internal threads of the flange. With this provision, the relative vertical position of the shock absorber with respect to the dome-support-plate and by extension the ground level can be adjusted to suit the level set by the barrel-nipple-end. The 5.8cm diameter central rod passes snuggly through the 5.84cm central hole of the pipe. The very close fitting is essential in preventing unwanted vibrations in the system. The main spring and the central rod are also hanging on a nut on the central rod hanger which is resting on two stainless steel auxiliary springs, sitting on top of the pipe. It should be noted that the diameter of the lower part of the pipe is reduced to provide a tight sitting for the top part of the main spring and eliminate secondary vibrations at that end. The lower end of the pipe and the lower end plate of the central rod therefore acts as stoppers to the main spring. The main spring is 44cm long with an external diameter of 12cm, internal diameter of 9cm and stiffness of 33000Nm^{-1}. The thread stopper (nut) at the upper end of the central rod prevents it from falling off when the dome is jacked up. The two 10cm high by 10cm wide auxiliary springs between the nut and the upper end of the pipe are also provided to attenuate secondary vibrations, after firing the shot. Two dome-hangers are bolted at opposite ends of the external side of the cylinder, 2cm from the top end, by six gauge-17 bolts. It is through these dome-hangers that the entire cannongun dome can be jacked up or down.

Carriage

The support frame (part 7) of the carriage system is made from pairs of 6cm by 6cm angular steel bars boxed-up by welding to form square pipes. The left and right sides of the support frame, has two square pipes each. The outer pipes are used to couple the tyres to the carriage while the inside pipes are used to support the two rotary jacks (part 23) and to guard the dome casing so that it does not swing heavily during transportation. Two "Beetles" car wheel hubs (part 8) are welded onto the outside pipes of the support frame and are fitted with "Beetles" rim (part 9) and tyres (part 10). The dome-hangers are seated on the upper part of the jacks. Two rods connected to each of the jacks have a system of two gear toothed plates and a chain (not shown) which is connected in such a way that by turning just one handle the two jacks are simultaneously raised or lowered depending on the direction the handle is turned. The new cannongun source is pulled around by a 3cm diameter black pipe (not shown) bent into a half-rectangle and welded onto the outside pipes of the support frame. The half-rectangle pulling handle is 72cm wide and 110cm long, and is inclined at an angle of 30° to the support frame. Two carriage support legs are also attached such that one is at the centre of the pulling handle end while the other is at the front end of the carriage support frame to help keep the entire system in a stable position before the dome is jacked up or down. Also, at the front end of the carriage system is a towing socket, which could be used to tow the cannongun source to a distant place.

Method of operation

For a start, the shot hole is augered first. An anti-vent foam is then spread in such a way that its central opening corresponds with the mouth of the shot hole. Thereafter the barrel with pre-loaded chamber is planted into the shot hole. Usually we preload eight chambers before going to the field, however that depends on the number of channels your seismograph has. The next step is to pull the carriage to the proper position and release the carriage support legs which keep the support frame steady. The dome is then jacked down to position such that the shock lower end plate rests firmly on the barrel nipple end. If all is set, the switch of the 9V (or 12V) power pack is closed to energize the blaster (part 19) and fire the shot. The blaster is made up of a constantan coil which is enmeshed in a sensitive explosive powder, housed in a 1cm diameter cylindrical plastic casing. After the shot, the seismograph records the signal. The dome is jacked up and pulled out for the barrel to be loaded with another chamber and fired as described earlier, if need be.

Repeatability

A repeatability test of the cannongun source was undertaken at two sites. The first repeatability test was carried out at the Unical test site; (University of Calabar) (Figure 3).

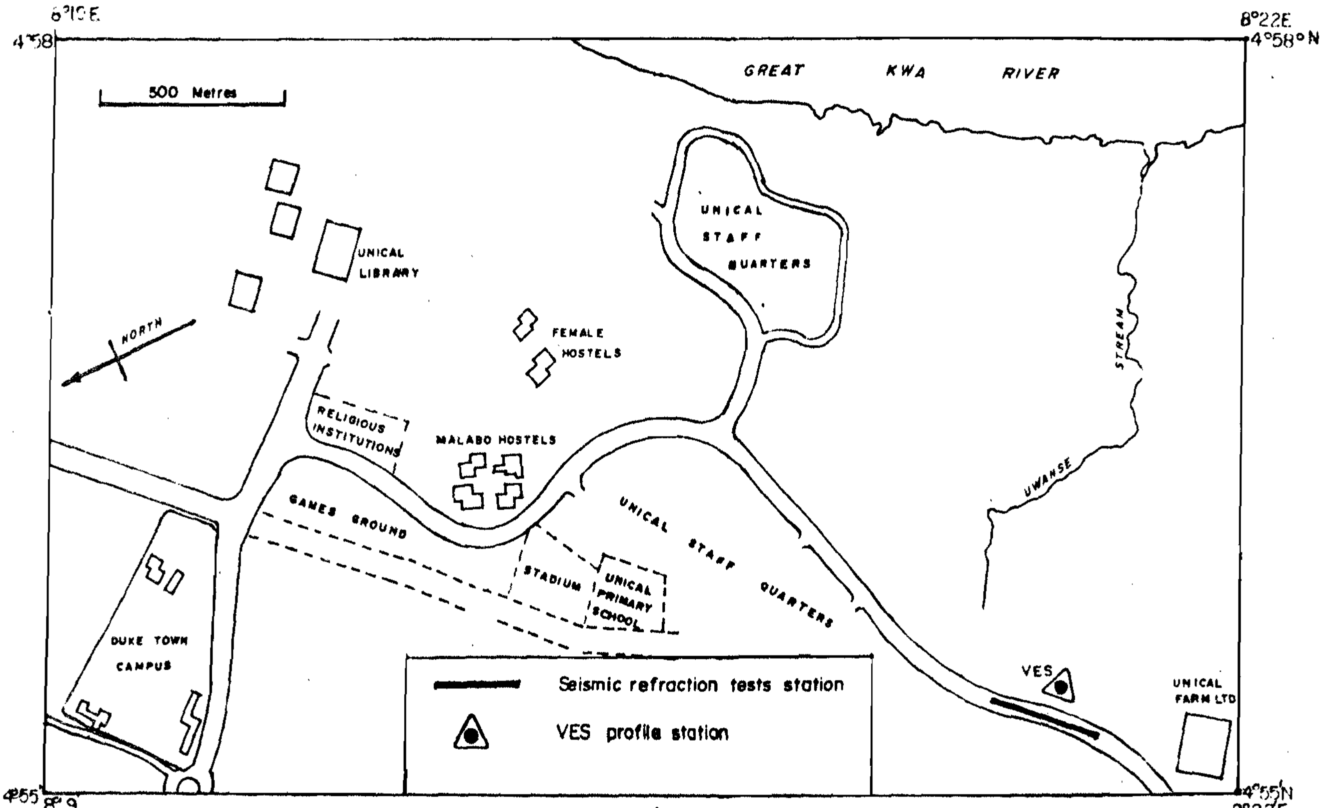
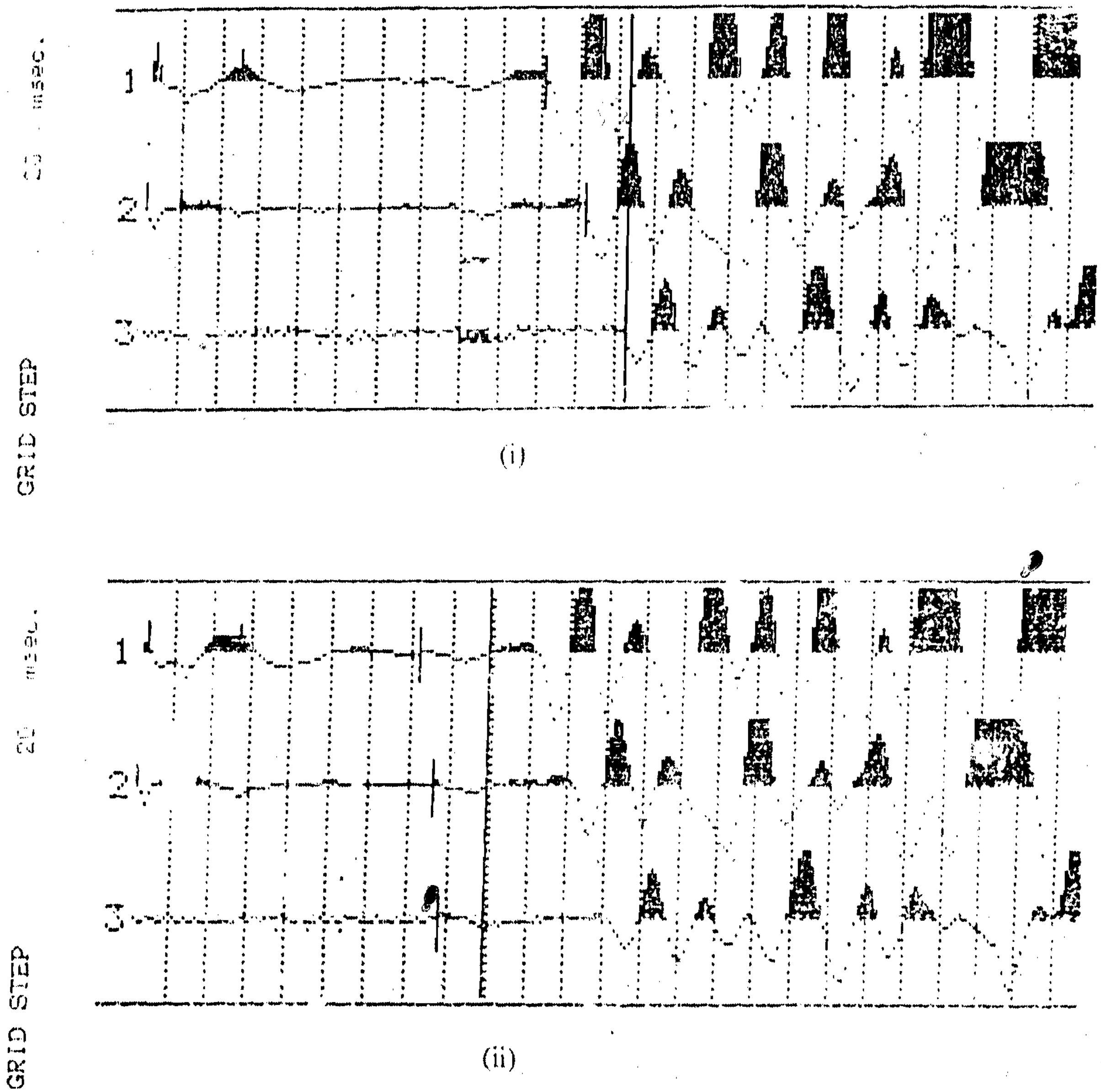


Fig. 3: University of Calabar (UNICAL) test site.

This site is located on the Coastal Plain Sands of the Calabar flank. A 3-channel Mod. S79 digital enhancement seismograph was used for data acquisition. The three 20Hz geophones used were planted firmly at 100m, 110m and 120m offsets. One shot each was fired and recorded for comparison as shown in Figure 4. The two seismograms were found to be similar in terms of first arrivals and wave shape. This shows that the cannongun source can be reliably used with a signal enhancement seismograph in surveys where vertical stacking in the field is required. The same type of experiment was done, at the Odukpani test site (Figure 5) which is sitting on the Nkporo shales (Ekwueme et al., 1995). The result of the Odukpani test is as shown in Figure 6. The records of the test shows that the signals are very much the same. Geophones for this second test were planted at 130m, 140m and 150m offsets. The Odukpani test confirms that the new source is repeatable in different geologic environments.



(i)

(ii)

Fig. 4: A repeatability test at the proposed Engineering Faculty test site (Unical). The geophones were planted at 100m, 110m, and 120m offsets. The seismograph of the first shot at the site is labelled (i), while that of the second shot is labeled (ii). The grid step is 10ms.

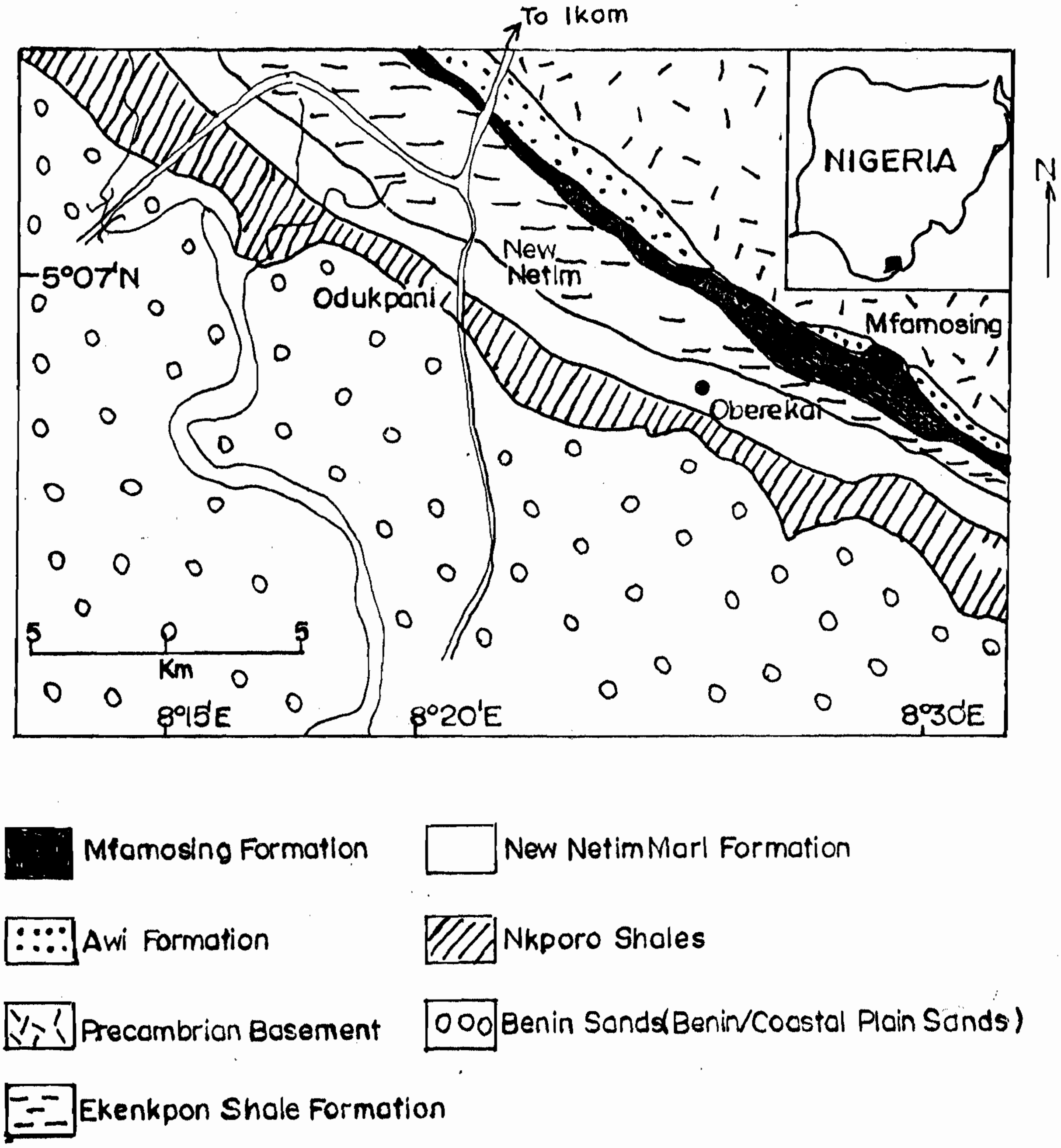
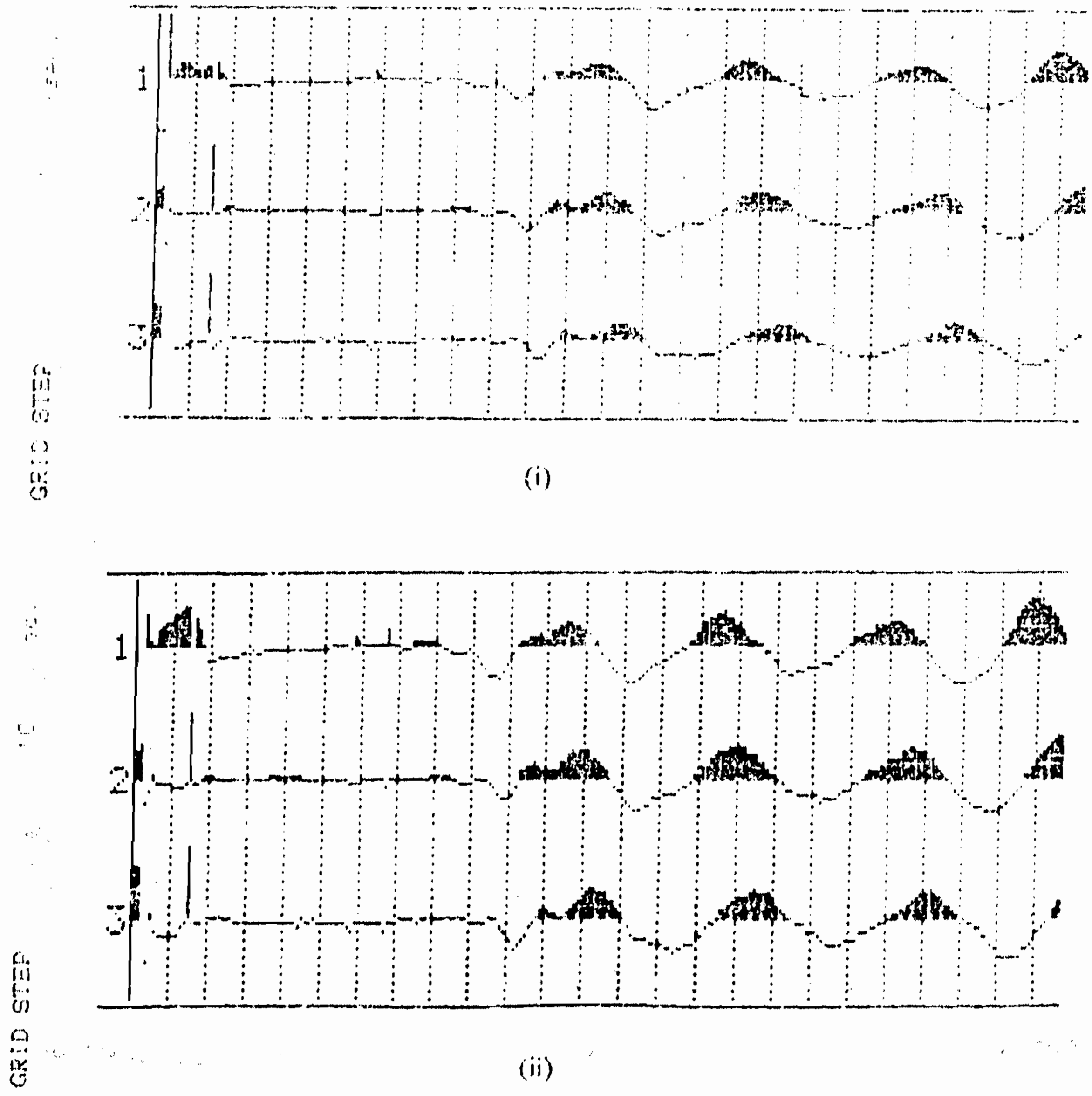


Fig. 5: A Geologic sketch map of part of the Calabar Flank, locating Odukpani and showing distribution of major lithologic units (After Ekwueme et al., 1995)



(i)

(ii)

Fig. 6: A repeatability test at Odukpani Headquarters test site. The geophones were planted at 130m, 140m and 150m offsets. The seismogram of the first shot at this site is labelled (i), while that of the second shot is labelled (ii). The grid step is 10ms.

Energy range

The source energy range test was done at the Odukpani test site using the seismic refraction model as the basis. The aim is to find out the farthest offset at which the geophone can still pick the first break for the cannongun in comparison to the sledgehammer and to deduce a geophysical perception of the relative depth each source can probe under the same geologic situation. The maximum possible offset for the sledgehammer at this site was 110m, while the cannongun gave a good record at 190m (which is the maximum length of the cable used). The uncorrected seismic section for the cannongun source is shown in Figure 7, while Figure 8 is that of the sledgehammer. The onset of the first troughs of the first arrivals were picked for consistency, but were later corrected by subtracting time values corresponding to the average time intervals of the crests of the first break signals. The seismograph of a cannongun shot with geophone offsets at 170m, 180m and 190m is shown in Figure 9, for clarity. Table 1 shows the picked and corrected arrival times for both sources. Analysis of the times of first arrivals picked from Figures 7 and 8 shows that the cannongun delineated a second refractor at a depth of 90m, while the sledgehammer could not image this refractor. The T-X plot for the cannongun and sledgehammer data are shown in Figures 10 and 11

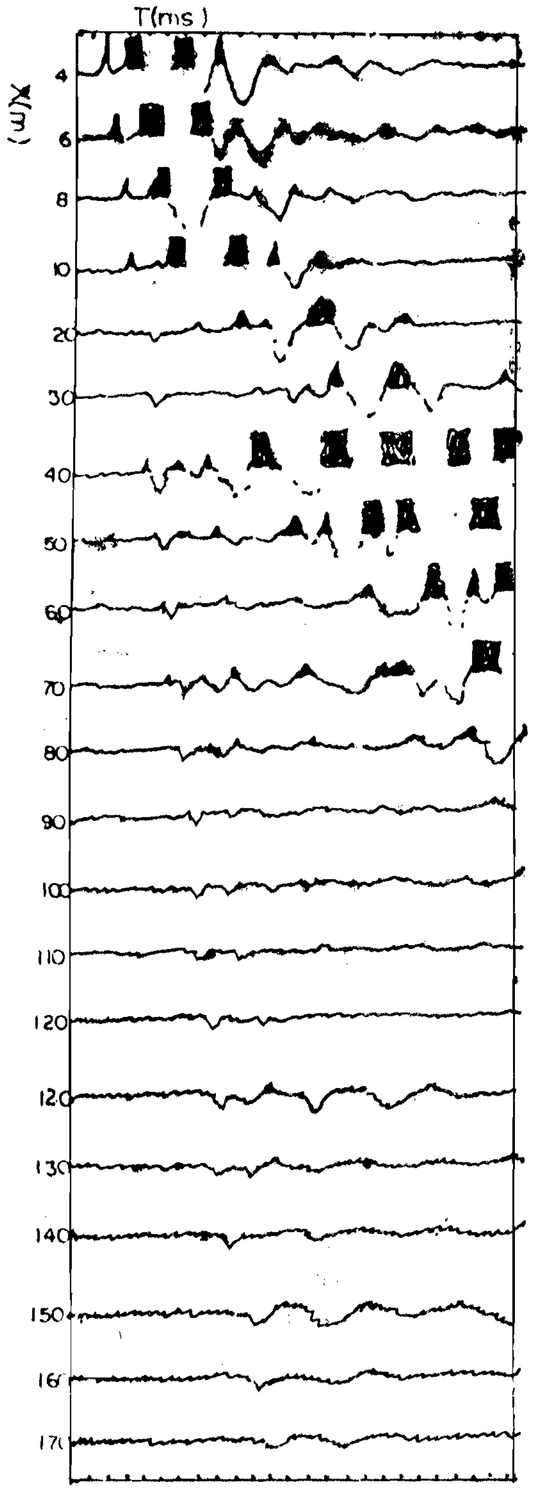


Fig. 7: Uncorrected seismic section acquired at Odukpani Headquarters tets site using the cannongun source. The grid step is 10ms while the record time is 250ms.

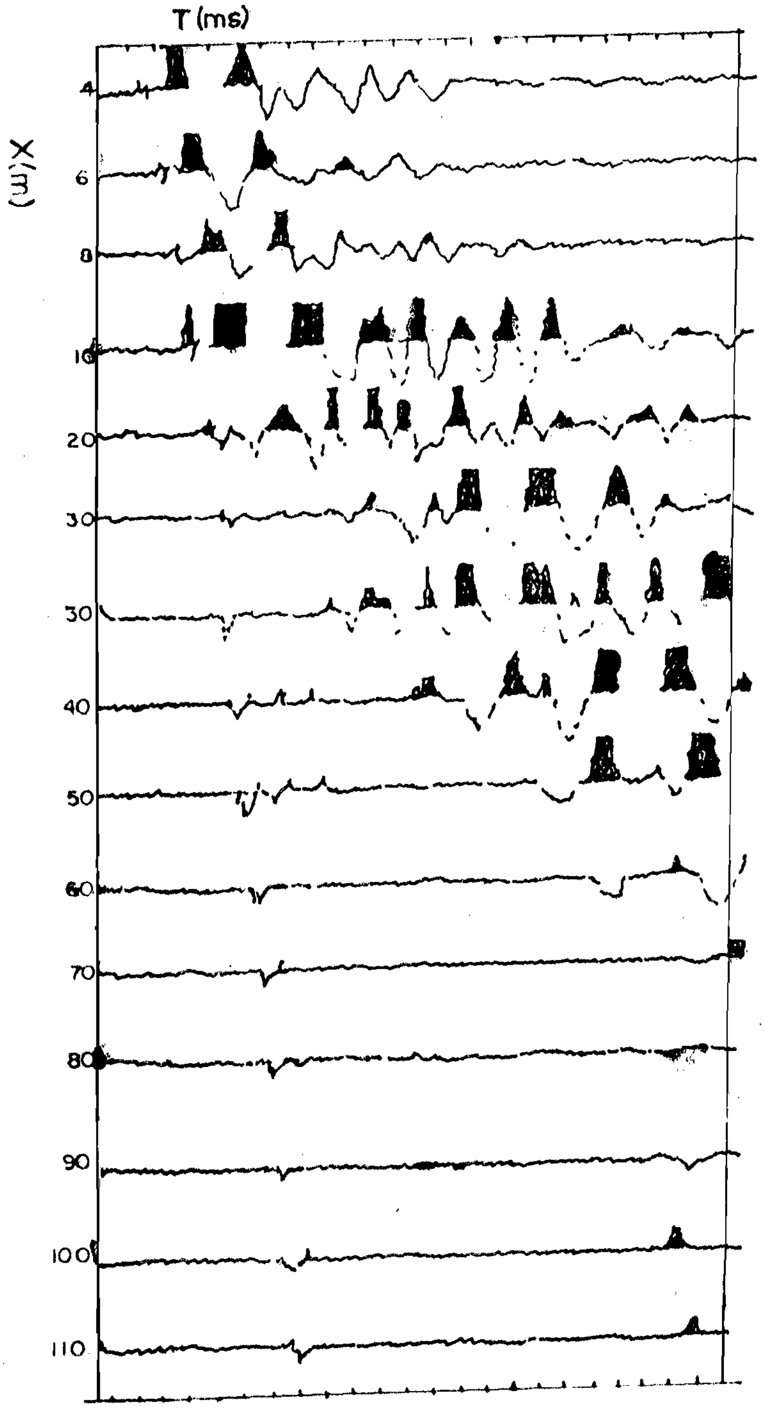


Fig. 8: Uncorrected seismic section acquired at the Odukpani Headquarters test site using the sledgehammer source. The grid step is 10ms, while the record time is 250ms.

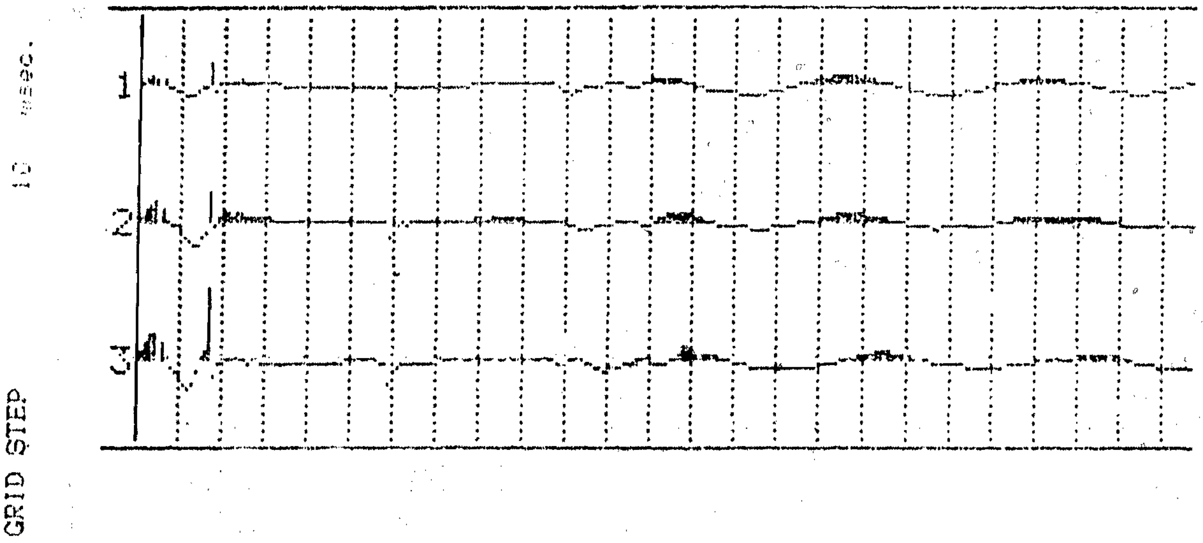


Fig. 9: Seismogram of a cannongun shot with geophone offsets at 170m, 180m and 190m. The grid step is 10ms, while the record time is 250ms.

Table 1: Refraction arrival times for the cannongun and sledgehammer.

	Cannongun data		Sledgehammer data	
Offset Distance X(m)	Picked Arrival Time T (ms)	Corrected Arrival Times T (ms)	Picked Arrival Time T (ms)	Corrected Arrival Times T (ms)
4	19	13	17	11
6	24	18	26	20
8	30	24	30	24
10	34	28	36	30
20	39	33	43	37
30	43	37	47	41
40	47	41	51	45
50	51	45	55	49
60	56	50	60	54
70	60	54	64	58
80	63	57	67	61
90	67	61	71	65
100	71	65	75	69
110	75	69	78	72
120	77	71	-	-
130	82	76	-	-
140	86	80	-	-
150	88	82	-	-
160	-	-	-	-
170	96	90	-	-

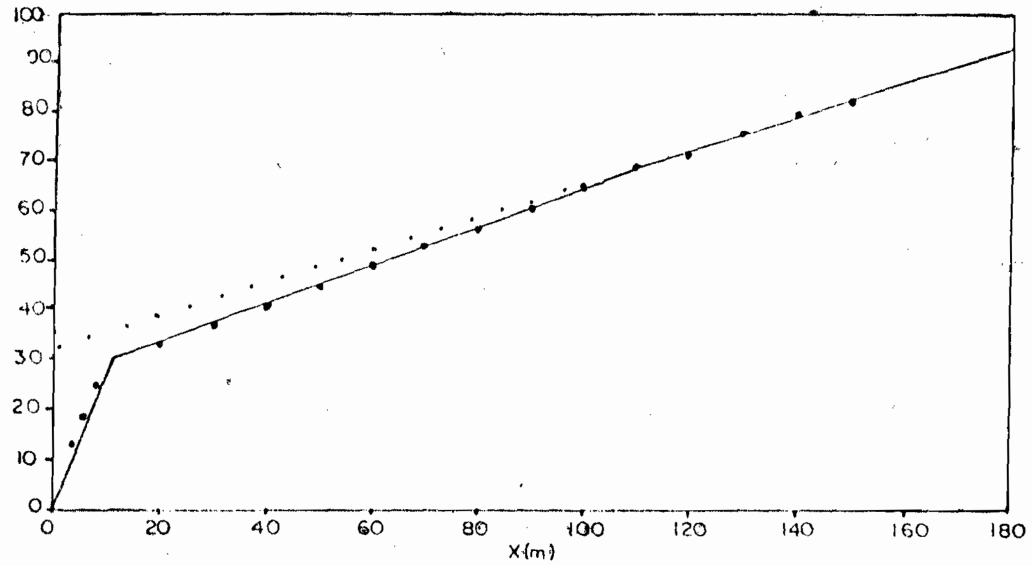


Fig.10: T–X plot of the cannongun data.

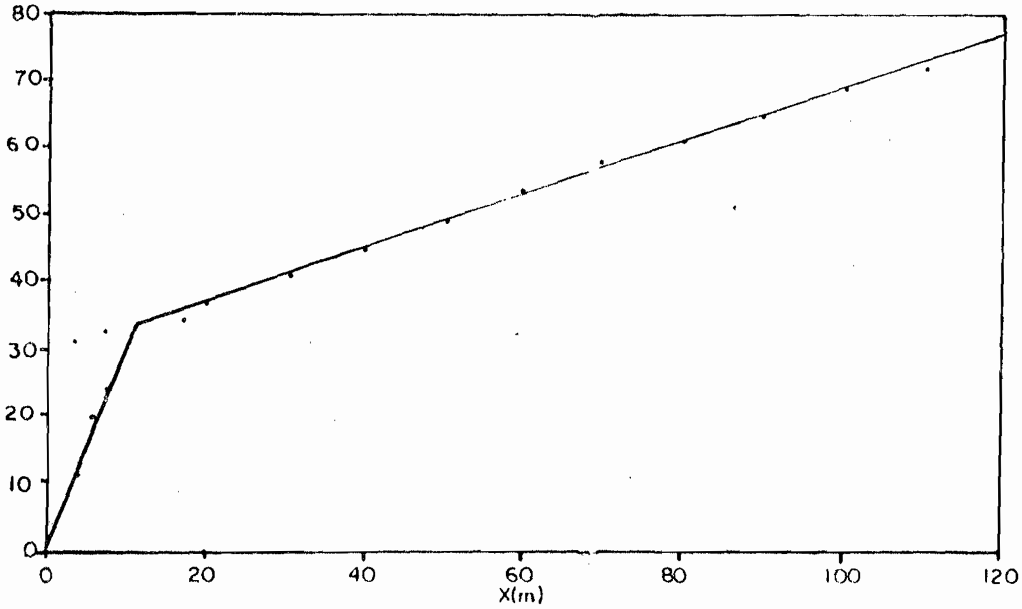


Fig.11: T–X plot of the sledgehammer.

respectively. The intercept times for Figure 10 are 25.7ms and 31.4ms respectively, while the intercept time for Figure 11 is 29.4ms. Derived velocity values and layer thickness values are shown in Table 2, for comparison. The large error values are basically due to the relatively few number of sampling points (i.e. geophone locations) used.

Maximum charge size

Initial tests were performed at the proposed Unical Biology Building test site with 300 grains charges. After 30 successful shots we were convinced that the cannongun is functional. The final stage of the test took place at the Unical Faculty of Engineering test site. At this site, the charge size was gradually increased until a charge slightly above 1000 grains (200KJ; Parker et al., 1993) of black powder explosive was fired. First a 50 grains charge was fired, then a 300 grains charge, a 550 grains charge, an 800 grains charge and an approximately 1000 grains charge. It was found that the dome did not bounce for the first four shots. But when the ~1000 grains shot was fired the dome-support plate was observed to bounce. The charge was deliberately made slightly more than 1000 grains so that the bouncing will be clearly evident. The ~1000 grains charge size firing was repeated three times and the same result was observed. In any case, when the same (~1000 grains) charge size was used but not well tamped, the dome-support-plate did not bounce. This shows that the explosive potential energy of the black powder can only be effectively utilized if the charge is well compacted and tamped.

Table 2: Derived velocities and layer thickness values, with the calculated error Bar.

Velocity (V) / Thickness (Z)	Cannongun	Sledgehammer
V_1	392 ± 39 ms^{-1}	328 ± 70 ms^{-1}
V_2	2564 ± 64 ms^{-1}	2532 ± 56 ms^{-1}
V_3	2915 ± 395 ms^{-1}	-
Z_1	5 ± 1 m	4.9 ± 1.4 m
Z_2	85 ± 12 m	-

DISCUSSION

It is not in all sites that a seismic refraction based evaluation test can be undertaken successfully. The test site must be located in a place where the velocities of the rock layers do not only increase with depth but produce noticeable contrast between layers. That was why Odukpani site was chosen.

The non-availability of a 24-channel or at least a 12-channel seismograph at the time of the evaluation tests almost made a mess of the relative advantage of the cannongun source. For instance, it will take 8 separate shots to record for 24 data points with the 3-channel seismograph used. But with a 24-channel seismograph, one shot will do the job except where enhancement is required, then at most three shots will be enough. Again, with a 24-channel seismograph, the effect of the possible gradual change in shot hole characteristics will not be localized on a small part of the seismic section but will be evenly spread. The non-availability of required equipment was partly the reason why frequency content was not considered as an evaluation parameter. However, from the works of other colleagues like Pullan and MacAulay, 1987; Parker et al., 1993; and Miller et al., 1994, it is obvious that guns and related explosive sources generate seismic waves with enough high frequency components for shallow reflection and refraction work. Since the evaluation tests for this paper is refraction based, we decided to rest the issue of frequency content until we acquire all the required equipment to be able to embark on shallow reflection based evaluation tests.

Seismic refraction data is usually plagued with the difficulty in picking correct first arrivals due to the attenuation of the head waves with increasing offset. This phenomenon tends to make first arrivals at farther offsets to appear to have arrival times that are higher than the true values. To correct for this, the arrival times were first picked at the equilibrium point, between the first crest and trough. This is done because the said equilibrium point is clear and consistent for all traces. The picked values are later corrected by subtracting the average time for the width of the crests from them (see Table 1).

It was noticed that the arrival times of the first breaks for the sledgehammer came later than that of the cannongun for greater offsets. This may be due to the fact that the active device (Chamber) of the cannongun source is planted in a 1m hole, while the base plate of the sledgehammer is located at the surface.

The total cost (excluding discarded designs and personal labour costs) of production of the prototype cannongun source is about N40, 000 (~$250), which is fair enough considering the usual cost of producing prototypes. The cannongun is operationally cost effective. A N300 black powder (one bottle) can be comfortably used to fire 8-shots. Also a N240 worth of dry cells (4 pairs of 1.5V batteries) can be used to fire about 25 shots or more, depending on the quality of the batteries.

CONCLUSION

As has been earlier noted, the cannongun is repeatable. This is good from the point of view of vertical stacking. It is also a mark of reliability in terms of arrival time values. Again, the fact that the can image the subsurface up to a total depth of 90± 13m with a single shot per trace, shows that it is an efficient seismic energy generator. Of course, it has been shown by Miller et al., (1992) that at an excellent seismic-data site, source selection is critical only in relation to total energy necessary to image the geologic target. It can therefore be inferred from this research, that the energy of the cannongun is well suited for imaging geologic targets at depths beyond the range of lower energy sources like the sledgehammer.

A lot of technical and operational successes were recorded in the adaptation and testing of the cannongun source. One of the outstanding ones is the ability of the source to confine almost all of its explosive potential energy to the ground, when the shot is fired. However, the most thrilling technical success to us, is in the operation of the silencer mechanism. The sound of the explosion is almost totally subdued and there is no question of fall back of debris on geophones as in the case of conventional explosives fired in mud filled shot holes. Cannongun seismic source is in this wise environmentally friendly. It is practically devoid of noise pollution occasioned by the very loud noise associated with explosive sources. Also the system is very safe and posses no danger to nearby structures, though it is invasive. Of course, the maximum of 1m invasion of the subsurface for planting the barrel is not too significant as to preclude its use.

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