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THE CONSTRUCTION OF A CASED BOREHOLE FACILITY FOR THE PURPOSE OF TILT OBSERVATIONS AT CHARLEVOIX OBSERVATORY, QUEBEC

John Peters
Oceanography Department
Dalhousie University

DOSSIER PUBLIC DE LA DIRECTION DE LA PHYSIQUE DU GLOBE 83-21
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Ottawa, Canada, 1983

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This is the final report on work performed
by J. Peters, Oceanography Department, Dalhousie University
for the Earth Physics Branch under
DSS Contract 20SU 23235-1-1003
February, 1983

Ceci est le rapport final du travail executé par
J. Peters, Oceanography Department, Dalhousie Univesity
pour la Direction de la Physique du Globe sous le
Contrat 20SU 23235-1-1003
Février, 1983

THE CONSTRUCTION OF A CASED BOREHOLE FACILITY FOR THE PURPOSE OF TILT OBSERVATIONS AT CHARLEVOIX OBSERVATORY, QUEBEC.

Author: John Peters
Oceanography Department, Dalhousie University

DSS Contract 20SU 23235 - 1 - 1003

Final Report February 28, 1983

1. INTRODUCTION

This report describes the work performed in establishing a third cased borehole facility for tilt observations at Charlevoix Observatory. In section two the technical rationale for the project is presented followed by a description in section three of the borehole design. Section four summarises the progress of the work and outlines the schedule for operation of the borehole facility.

2. TECHNICAL RATIONALE

It has been amply demonstrated (see for example, Zschau, 1976, Cabannis, 1978, Herbst, 1979) that the burial of tiltmeters to depths beyond 20m dramatically improves signal to noise ratio. The signal of interest is regional tilt and the noise is generally dominated by two phenomena: 1) meteorologically induced tilts (caused by temperature and rainfall effects) which most seriously affect the secular part of the signal, and 2) strain - tilt coupling which causes modification of the tidal admittance due to the departure of the local rocks from an ideal, homogeneous half-space. Strain-tilt coupling is a particularly serious problem in cases where short baseline installations are used (Baker, 1980) and near the surface where the rocks are highly heterogeneous. Both noise sources can be adequately reduced at the surface by increasing the instrument baseline to dimensions comparable with geodetic work, namely

Abstract

The report describes the work performed in establishing a third cased borehole facility for tilt observations at Charlevoix Observatory. It includes the technical rationale, a description of the borehole design and the progress of the work to date.

Resumé

Ce rapport décrit la methode utilisée pour l'établissement d'un troisième dispositif pour des observations clinométriques à l'observatoire de Charlevoix. Le rapport presénte la raison d'être du projet suivit du concept du puits de forage et le progrès accompli à date.

one kilometer. This approach has been successfully pursued at Pinon Flat by Wyatt et al (1982) whose water tube tiltmeter spans 800m.

Our approach at Charlevoix is to increase the depth of installation to increase the isolation from meterological effects and at the same time employ an installation technique which effectively ensures a measurement baseline of six meters or more. The borehole method has a number of advantages over the long baseline surface approach. Firstly, a proven instrument, the Bodenseewerk Gbp 10 tiltmeter, is available commercially and therefore little instrument development is required. The logistics of borehole installation are much less complicated than for the surface long baseline tiltmeter. In particular, much less real estate is required. Finally, the performance of borehole installations has been shown to be the most consistent to date both in terms of long term stability and spatial coherence of the tidal admittance (Zschau 1976, Cabannis, 1978, Flach et al, 1975). Indeed, a comparison of the water tube tiltmeter at Pinon Flat and an ADL borehole tiltmeter installed at 30 m at the same site showed good agreement for the tidal results and only a slightly degraded borehole secular tilt performance (Wyatt et al, 1982).

At Charlevoix, it has been established (Peters and Beaumont, 1982) that the borehole secular tilt (based on data from borehole 1 during September 1980 to April 1981) is dominated by hydrologically induced tilts. Figure 1 shows the secular tilt for the South and East tilt components plotted in conjunction with rainfall and manual measurements of water level in deep well number 1. It is apparent that the water level is changing in response to rainfall and that the tilt is responding principally to water level. A first order correction for this effect is estimated to leave a residual secular tilt at the 0.1 to 0.2 microradian level.

Comparison of the borehole secular tilt with that deduced from the surface levelling array data (Gagnon et al, 1980) indicates a dramatic attenuation with depth of hydrologically induced tilts. Buchbinder et al (1983) show that the levelling array tilt variations are largely correlated with water level. Comparison of the trajectories of the array tilt and the borehole 1 tilt (figures 2 and 3) indicate an order of magnitude attenuation at 46 m depth and an approximately 100 degree difference in the azimuth of the response.

On the basis of the results of the above comparison and the belief that fracture permeability reduces significantly with depth, we decided to drill the third borehole in the Charlevoix Observatory borehole array to a depth of 150 m rather than the planned 50 m. Our hope is to further reduce the hydrologically induced tilts and thereby increase the detectibility of tectonic tilts. The additional costs required to accomodate the deep borehole configuration are covered within this contract.

3. BOREHOLE DESIGN

The basic design of the third borehole installation is the same as that for the two existing holes. Figure 4 is a schematic of the essential features. A 20 cm diameter mild steel casing string consisting of six meter welded sections is cemented in a 30 cm diameter straight hole. Welded to the bottom of the casing string is a stainless steel pod into which the tiltmeter is installed (see detail in figure 4). The tiltmeter rests on a pin supported within the pod. When the tension is relaxed on the tiltmeter cables three pins protrude sideways from the top of the tiltmeter and lock into the pod wall.

The tiltmeter requires azimuthal alignment and this is traditionally done optically by comparing the orientation of illuminated slits at the top of the tiltmeter with a reference line at the surface. To do this, line of sight down the hole to the instrument is required. In the case of the third borehole line of sight was not achieved due to drilling problems discussed later.

The problem was overcome by incorporating a fixed alignment muleshoe assembly within the pod (figure 5). A 15 cm diameter brass tube of sufficient size to pass the tiltmeter was centered over the support pin and fixed to the tiltmeter support platform. The tube was cut away at 45 degrees and at the lowest point of the contour a slot was milled. Fixed to the tiltmeter is a key which, as the tiltmeter is lowered into the muleshoe, follows the contour of the tube and falls into the slot. The instrument thus rotates into the slot and takes up a unique alignment the orientation of which is determined by a one-shot downhole gyroscopic survey. The repeatibility of the orientation will be ±0.25 degrees due to the clearance between the slot and the key. However, the principal uncertainty in the azimuth will be the error in the gyroscopic survey which is expected to be one to two degrees.

Construction of the stainless steel pod and subsequent modification with the muleshoe assembly were performed at the Earth Physics Branch.

4. WORK DESCRIPTION

A contract for drilling and casing of a 150 m deep 30 cm diameter borehole was let on October 12, 1981 to Les Puits du Quebec of Quebec City, and work began immediately. The company elected to use the rotary/percussion with air method, starting with a six inch diameter bit, widening to 8 inches and subsequently reaming the hole to 12 inches using a tricone bit (rotary only).

It was agreed that maintainance of the hole specifications (straightness and verticallity) be monitored periodically throughout the operation. The most effective method for testing straightness was to lower a ring of lights down the hole. However, this method was useful only to about 50 m after which muddy water refilled the hole faster than it could be pumped out. Verticallity was established within the first 10 m. Thereafter, straightness, wherever it could be determined, was a sufficient measure of continuing verticallity.

For depths greater than 50 m straightness was measured using a similar triangles approach. A dummy of nearly the hole diameter was suspended in the hole from a pully located a known distance above the top of the hole. The horizontal displacement of the dummy center as a function of depth was proportional to the horizontal displacement of the suspension cable relative to a grid located at the top of the hole. Naturally, the accuracy of this method diminishes with increasing depth. This was not, however, to become a problem since the deviation of the bottom of the hole relative to the top reached 10 cm, the hole radius, between the 60 m and 70 m levels. Not only was this unacceptable for the straightness specification, the similar triangles method no longer worked since the cable had reached the wall of the hole and no longer represented a straight side. When this was discovered the hole had been drilled to a depth of 90 m and had been reamed to 30 cm. A 15 cm diameter test hole was drilled nearby to a depth of 100 m and tested for verticallity. This hole, too, deviated in the same way at the same depth. The drillers at this stage retired for the winter, planning to start again in the Spring.

It is difficult to isolate the cause for deviation in the hole. The rotary percussion method was very successfully used to a depth of 50 m by another contractor. Indeed, Les Puits du Quebec also maintained tight specifications to that depth. The granite in the region is judged to be exceptionally hard. The drillers had initially proposed to use the cable tool method, apparently the optimum approach for straightness, but abandoned this in the interest of speed. Nevertheless, the rotary/percussion method combined with the use of a stabilizer (a long heavy unit slightly narrower than the hole and located immediately above the drill bit assembly) was expected to do the job. It was agreed, given the considerable difficulties encountered during drilling and the similar behaviour of the two holes at depth, that the formation was unfavourable and that further new attempts would be fruitless. We decided to accept the crooked hole and modify the stainless steel pod to permit a gyroscopically determined alignment.

The original proposal for the third borehole specified 150 m as the target depth. At 134 m, the drillers intersected a large fracture which pumped water into the hole at a high rate. This caused two problems. The recharge rate of water in the hole was so high that the drilling compressor could not develop the power to overcome the hydrostatic pressure in the hole. This may have been overcome by bringing in a more powerful compressor. More importantly, it is undesirable to locate a tiltmeter close to a dominant fracture since the measurement will likely be strongly affected by the behaviour of that fracture. The presence of such a feature at a depth of 130-140 m suggested that similar features may exist at deeper levels. Rather than risk intersecting another, or worse, drilling close to another fracture and not know about it, we decided to backfill from our present location to a depth 20 m above the intersected fracture. The final depth of the hole was 110 m.

Drilling was completed in May. Tiltmeter 106 was installed briefly at this time to test the verticallity of the hole. The only effective way of determining that verticallity is within specification is to demonstrate that the tiltmeter will operate. We estimated from the amount of relevelling required to centre the tiltmeter pendulum that the bottom of the hole is about two degrees from vertical. (It was later determined during the gyroscopic survey that the hole inclination is closer to 2.5 degrees, perilously close to the 3 degree limit for the range of the tiltmeter.) Installation and normal operation of the tiltmeter showed that the alignment assembly was functioning properly.

The casing was grouted in July and the hole surveyed by Sperry-Sun of Edmonton in November. Tiltmeter 105 was installed immediately afterwards and has functioned well on one channel (the West direction) since. The Y component requires some electronic modification before normal operation can be achieved.

Figure 6 shows the position of hole 3 relative to other installations at the site.

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FIGURE CAPTIONS

Figure 1: Plot against time of: groundwater level; borehole tiltmeter 105 secular tilt in X(east) and Y(north) directions; and rainfall for the period September 27, 1980 to April 10, 1981 (from Peters and Beaumont, in press).

Figure 2: Trajectory of tilt from the 40m baseline levelling array from June 1977 to February 1981 as deduced from monthly determination of a least squares plane fitted to the eight bench mark variations.

Figure 3: Trajectory of tilt from borehole tiltmeter 105 in hole 1 from September 1980 to March 1981.

Figure 4: Schematic diagram of a borehole and tiltmeter pod showing the basal support pin.

Figure 5: Photograph of the tiltmeter and muleshoe assembly. The key unit (at the base of the tiltmeter) and a centering device are shown on the tiltmeter. Note the contour and slot on the muleshoe.

Figure 6: Plan of the Charlevoix Observatory. The tiltmeter boreholes are labelled Hole 1, 2 and 3.

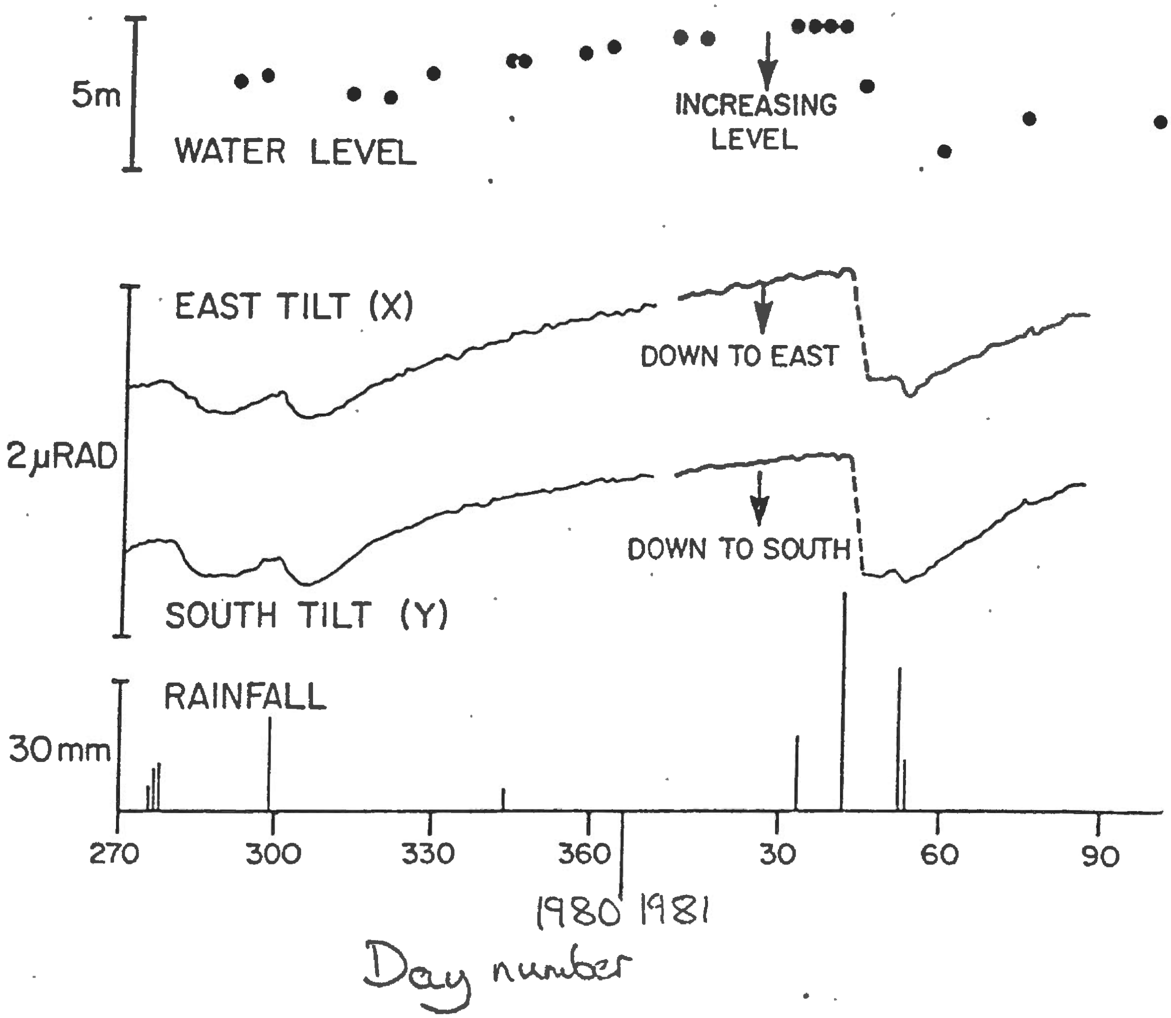

5m
WATER LEVEL
INCREASING
LEVEL
EAST TILT (X)
DOWN TO EAST
2μRAD
DOWN TO SOUTH
SOUTH TILT (Y)
RAINFALL
30mm
270
300
330
360
30
60
90
1980 1981
Day number

FIG 1

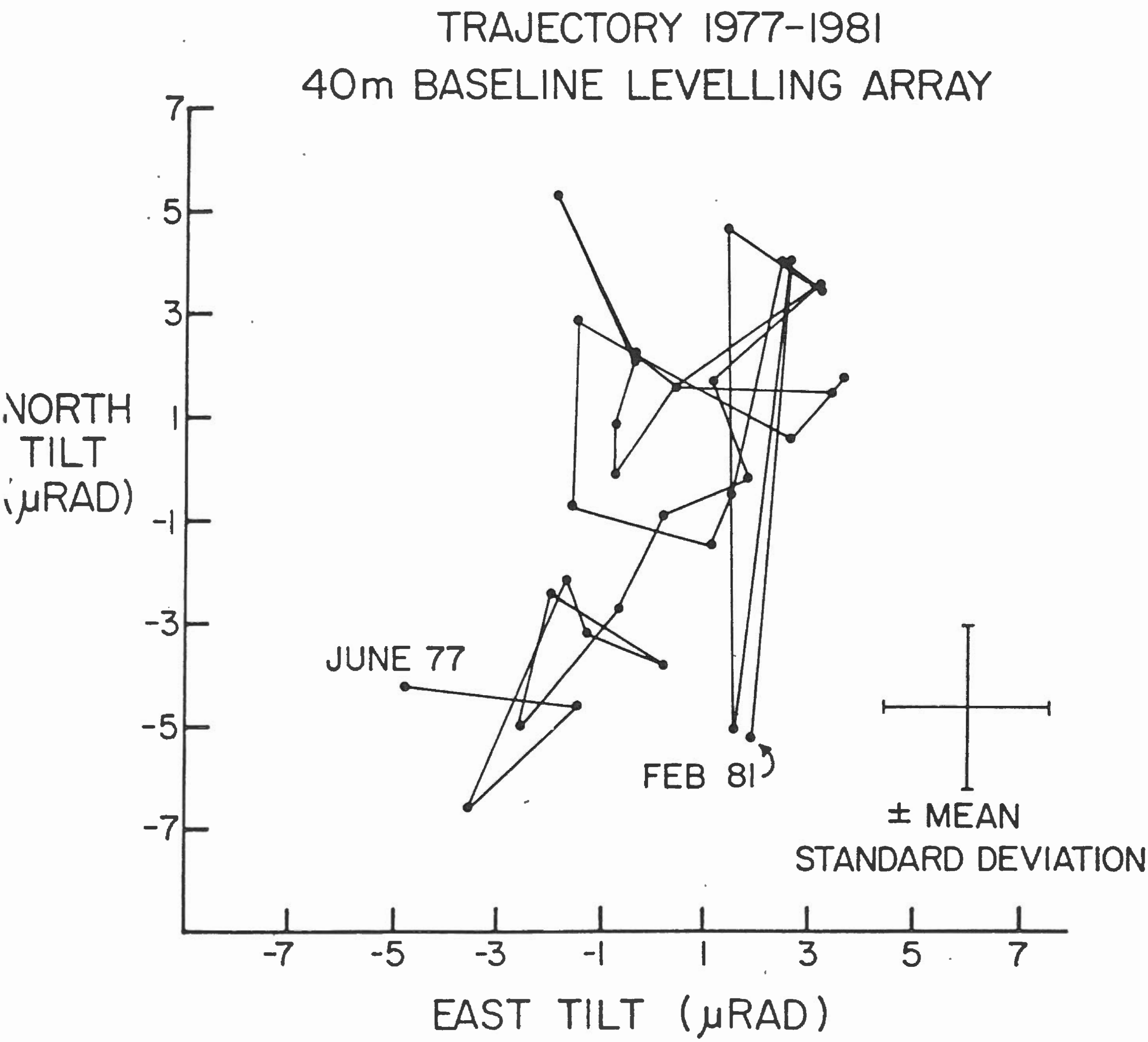

TRAJECTORY 1977-1981
40m BASELINE LEVELLING ARRAY
NORTH TILT (μRAD)
7
5
3
1
-1
-3
-5
-7
JUNE 77
FEB 81
± MEAN STANDARD DEVIATION
-7
-5
-3
-1
1
3
5
7
EAST TILT (μRAD)

FIG 2

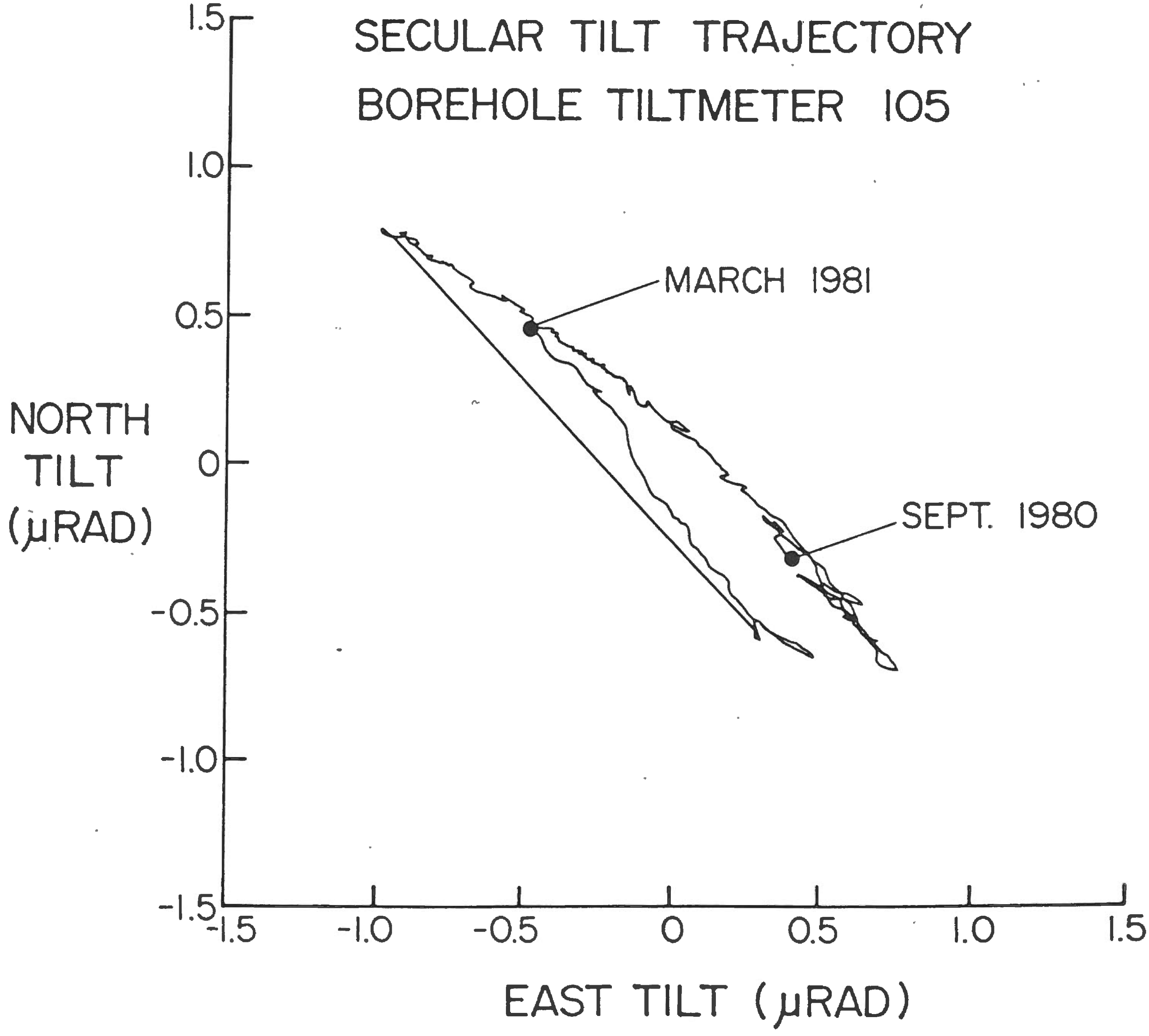

SECULAR TILT TRAJECTORY
BOREHOLE TILTMETER 105
MARCH 1981
SEPT. 1980
NORTH TILT (μRAD)
1.5
1.0
0.5
0
-0.5
-1.0
-1.5
-1.5
-1.0
-0.5
0
0.5
1.0
1.5
EAST TILT (μRAD)

FIG 3

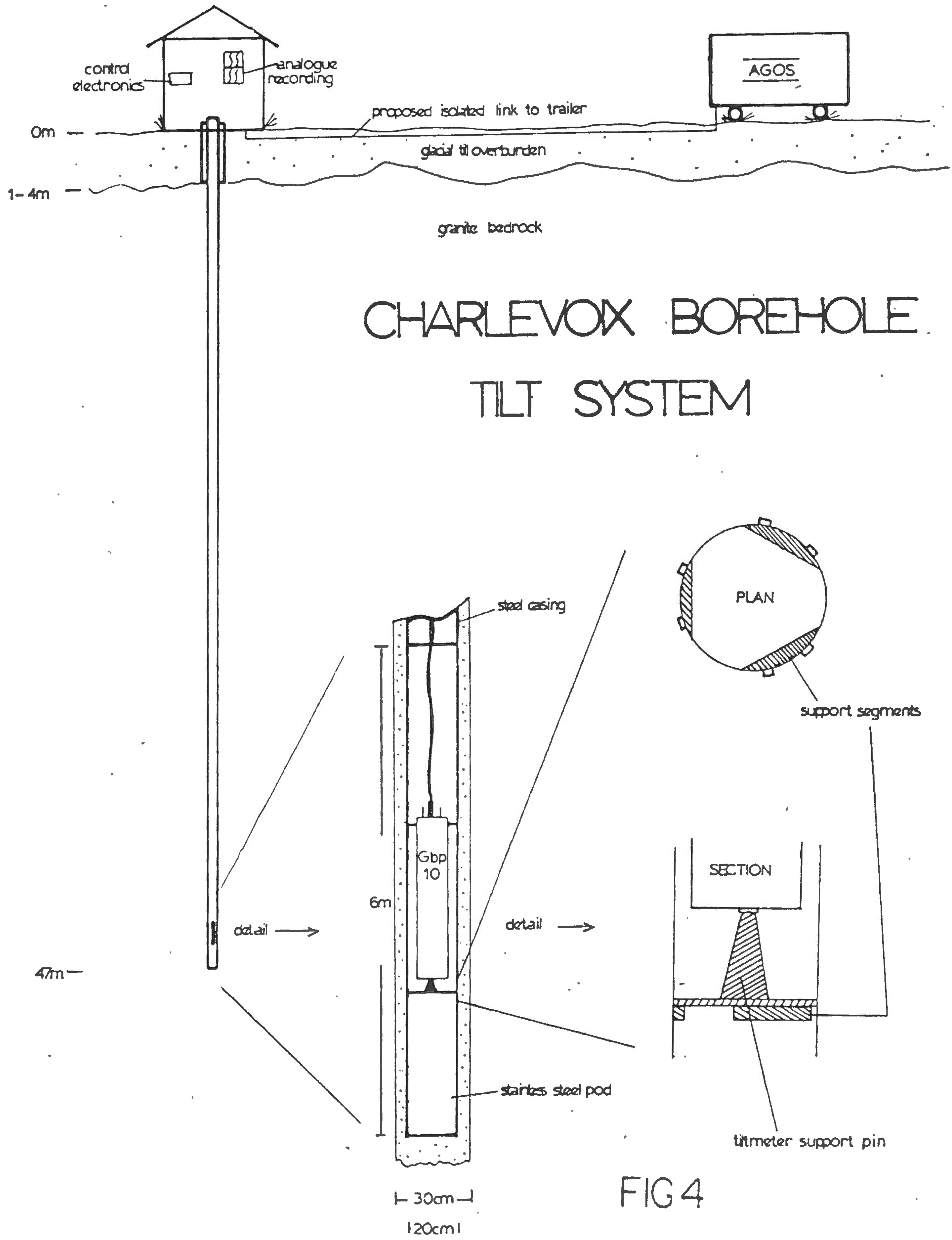

control electronics
analogue recording
AGOS
proposed isolated link to trailer
0m
glacial till overburden
1-4m
granite bedrock
CHARLEVOIX BOREHOLE
TILT SYSTEM
steel casing
PLAN
support segments
Gbp 10
6m
detail
detail
SECTION
47m
stainless steel pod
tiltmeter support pin
30cm
120cm

FIG 4

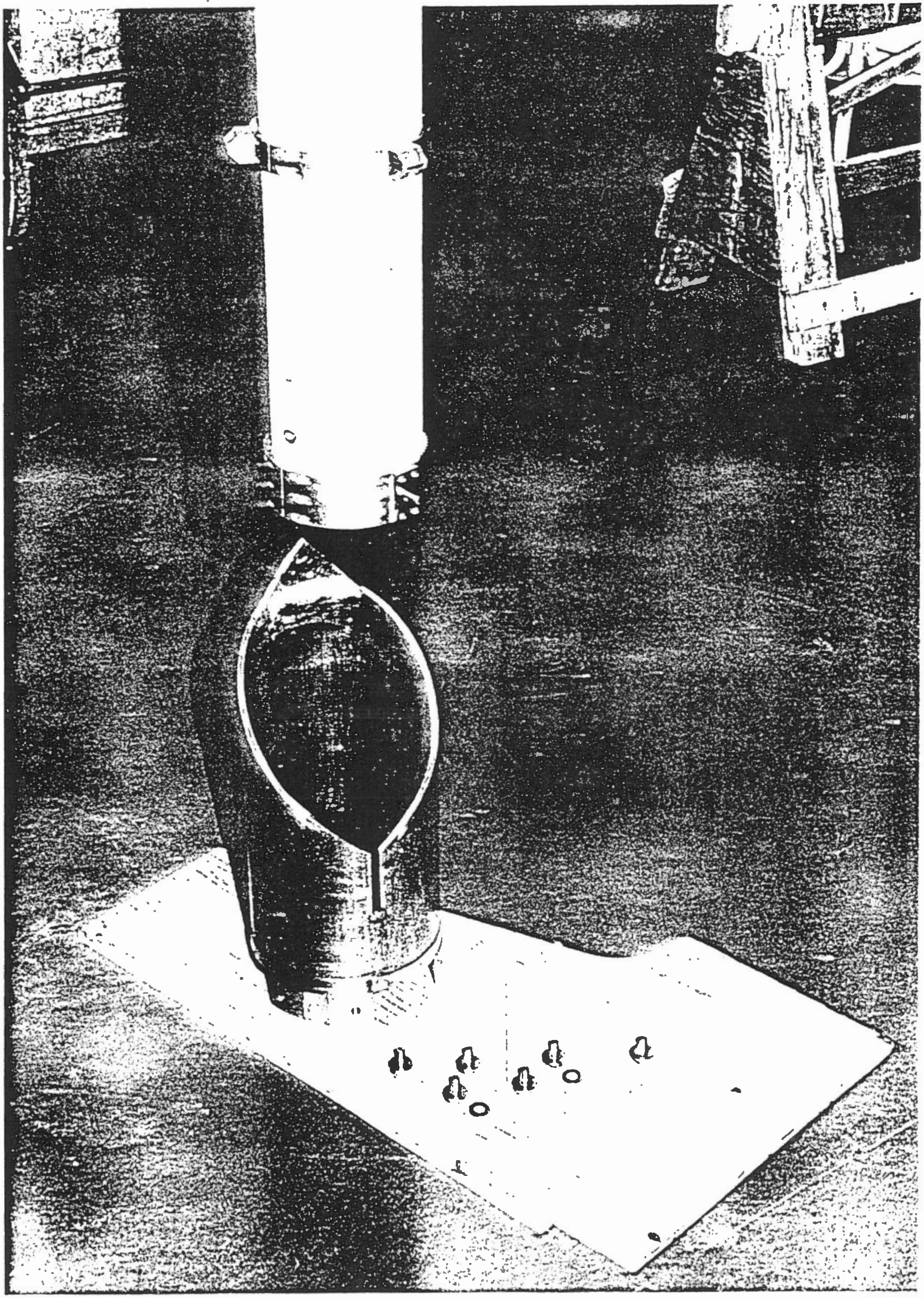
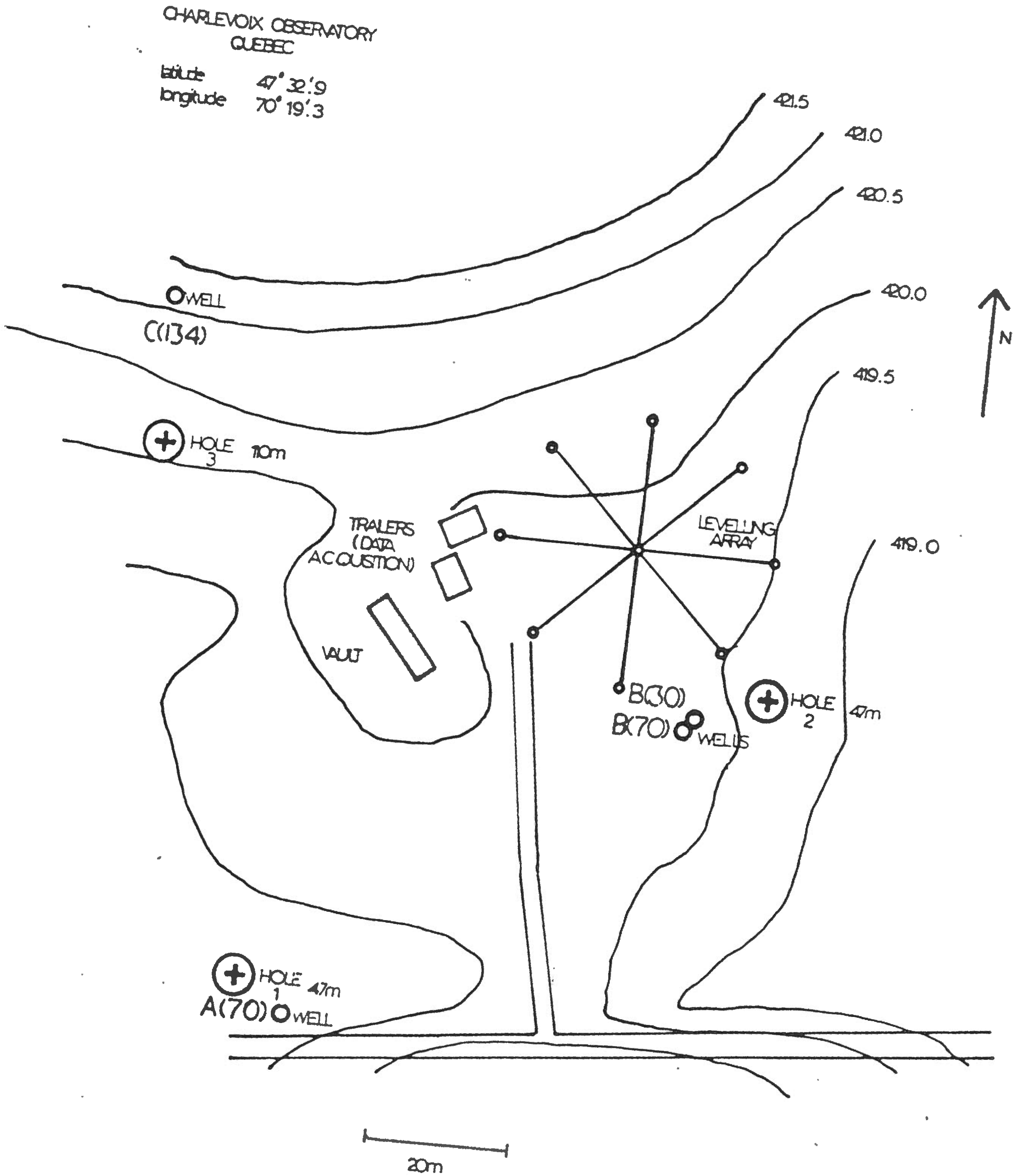


FIG 5



CHARLEVOIX OBSERVATORY
QUEBEC
latitude 47° 32.'9
longitude 70° 19.'3
421.5
421.0
420.5
420.0
419.5
419.0
N
WELL
C(134)
HOLE 3 110m
TRALERS (DATA ACQUSITION)
VAULT
LEVELLING ARRAY
B(30)
B(70)
WELLS
HOLE 2 47m
HOLE 1 47m
A(70) WELL
20m

FIG 6