A Geodetic Network For Crustal Deformation Studies At Manic 3 Quebec

by

M.T. Swanson

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An event larger than M5 is needed to result in displacements of a few cm under most favourable conditions. S.B.

M	max displ cm
5	≈1
6	≈5

A B S T R A C T

Precise measurement of distances, angles and elevation differences are used to establish a network of survey markers in the vicinity of the Manic 3 (P. Québec) dam site. The survey markers will be used as the reference points in future studies on crustal deformation. A statistical analysis of the adjustment results is used to estimate the magnitude of deformation that can be detected by geodetic measurements. The heavily wooded terrain affords an opportunity to examine a unique feature of a new type of survey tower.

S O M M A I R E

On a établi un réseau de points de repère dans les environs du barrage Manic 3 (Province de Québec) en se servant de mesures de distances, d'angles et de différences d'hauteurs. Ce réseau sera utilisé pour des études futures sur les déformations de la croûte terrestre. Une analyse statistique des résultats de la compensation a été faite afin d'estimer l'ordre de grandeur des déformations qui peuvent être décelées à l'aide de telles mesures géodésiques. La région boisée a permis d'examiner une caractéristique unique d'une nouvelle sorte de tour d'observations géodésiques.

I - INTRODUCTION

Scientists have long been aware of the phenomenon of induced seismicity. Several large induced earth tremors were known to have occured during the period 1930-1940 and several smaller since but they largely escaped the interest of those who should have been most concerned, partly because they were not considered a serious threat and partly because sensitive instrumentation needed for investigation was not readily available.

In the late 60's and early 70's, Hydro-Québec began to show an increasing interest in this field because of their involvement with large dams and reservoirs on the Manicouagan - Outardes River Systems and the James Bay project, *(Leblanc, 1976)*.

Meetings between officials from Hydro-Québec, Earth Physics Branch (EPB) of Energy, Mines and Resources (EMR) and the National Research Council resulted in a joint effort which placed accellerometers in the dams at Manic 5 and Manic 3 and established a single seismic station (MNQ), linked to Ottawa by telemetry, to monitor seismic activity at both dams.

In mid September of 1975 interpretation of the seismograms from MNQ showed several seismic events that were identified eventually as induced seismicity associated with the filling of the Manic 3 reservoir. In October of the same year increased seismic activity was noted and led to the prediction of an earthquake on October 23, which measured 4.3 on the Richter scale.

Interest and concern generated by these events led to a systematic study by EPB of several geophysical parameters to clarify the mechanism of induced seismicity. On the basis of these studies EPB decided to initiate a program of geomagnetic and microgravity measurements that could be correlated with seismic measurements and geothermal studies. It was also decided that the Surveys and Mapping Branch(S&M) of EMR should be approached to make precise measurements that would show any crustal deformations over a period of time, *(Leblanc, 1976)*.

Preliminary meetings between personnel from EPB and S&M were held in December of 1975. Firm commitments by both parties were finalized in March of 1976.

II - PLANNING AND PREPARATION

The 1976 field program of the Primary Horizontal Control Section of the Geodetic Survey was almost totally committed to strengthening the existing networks in preparation for the 1977 readjustment of the nation-wide primary framework. The Manic 3 proposal however, showed merit and urgency sufficient to be included in the program and was assigned to the party operating in Labrador - Northern Québec. It was anticipated that an advance party could deliver essential equipment and begin station preparation as early as July 1, when the scale control operations in Labrador would likely be complete.

FIGURE 1

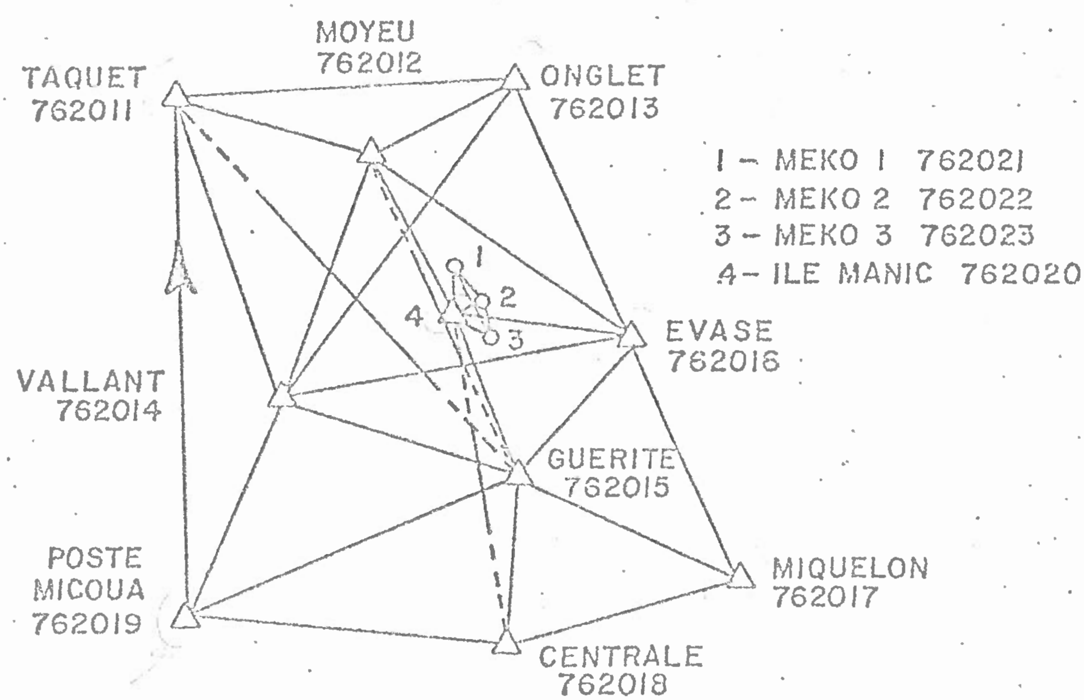
2.1 Preliminary Reconnaissance

Geodetic field officers visited the Manic 3 area in May 1976 to examine the terrain at the proposed stations that were within walking distance of ground transportation. Although the ground was still snow covered, the early reconnaissance provided the advance construction party with enough detail for planning with respect to tower requirements and monumentation at those stations.

2.2 Network Design

A number of factors influenced the design of the network. Primarily, consideration was given to the immediate and surrounding areas of suspected activity, as predicted from information gathered by EPB. Their information indicated a concentration of epicentres at about latitude 49^{0} 50.1' and longitude 68^{0} 36.7'. Using this as the approximate centre, stations were placed in the surrounding area so as to attain the desired density, a strong geometric figure, intervisibility with adjoining stations and rough symmetry about the river and about an east-west line through the centre of suspected activity. The resultant network is shown in Figure 2.

FIGURE 2



MANIC STRAIN POLYGON

1976

SCALE - 1:250,000

The strength of the network was determined by adjustment with HAVOC computer program in design mode. The following *a priori* standard deviations for distance measurements with the Geodimeters, direction measurements with the Wild T3 theodolite and azimuth determinations with the Wild T4 universal theodolite were used for weighting purposes in the simulation. All standard deviations are for first-order measurements as defined by *(S&M Branch, 1973)*.

Geodimeter Model 8 = $\sqrt{1 + (1.2\ L\ 10^{-4})^2}$ cm

Geodimeter Model 6BL = $\sqrt{1 + (1.2\ L\ 10^{-4})^2}\ \sqrt{3}$ cm

Wild T3 = 0.6 arcsecs

Wild T4 = $\sqrt{(0.8)^2 + (0.2 \tan \phi)^2 + (1.0 \sin \phi)^2}$ arcsecs

where L = length of line in metres; ϕ = latitude of the observation station.

The simulation showed standard error ellipses with semi-major axes of the order of 6 cm and semi-minor axes of the order of 1.5 cm. In all cases the orientation of the semi-major axes was such that an increase in precision of the length measurements would do little to reduce its dimension. The error ellipses also indicated that the standard error in position between two stations along a measured line was of the order of 1.5 cm, a precision that could hardly be improved on with equipment and techniques now available.

SE - w Δ ?

A meeting of EPB and S&M personnel was held to discuss the proposed network and the simulation results. EPB indicated that both the network and the precision would meet their requirements.

The following additions were later made to the network:

1) Three stations in the area of most probable seismic activity to provide several short lines, suitable for measurement by Mekometer.

2) A connection by first-order traverse to the existing first-order triangulation along the St. Lawrence River.

3) Connections to existing mapping control stations and concession boundaries in the area.

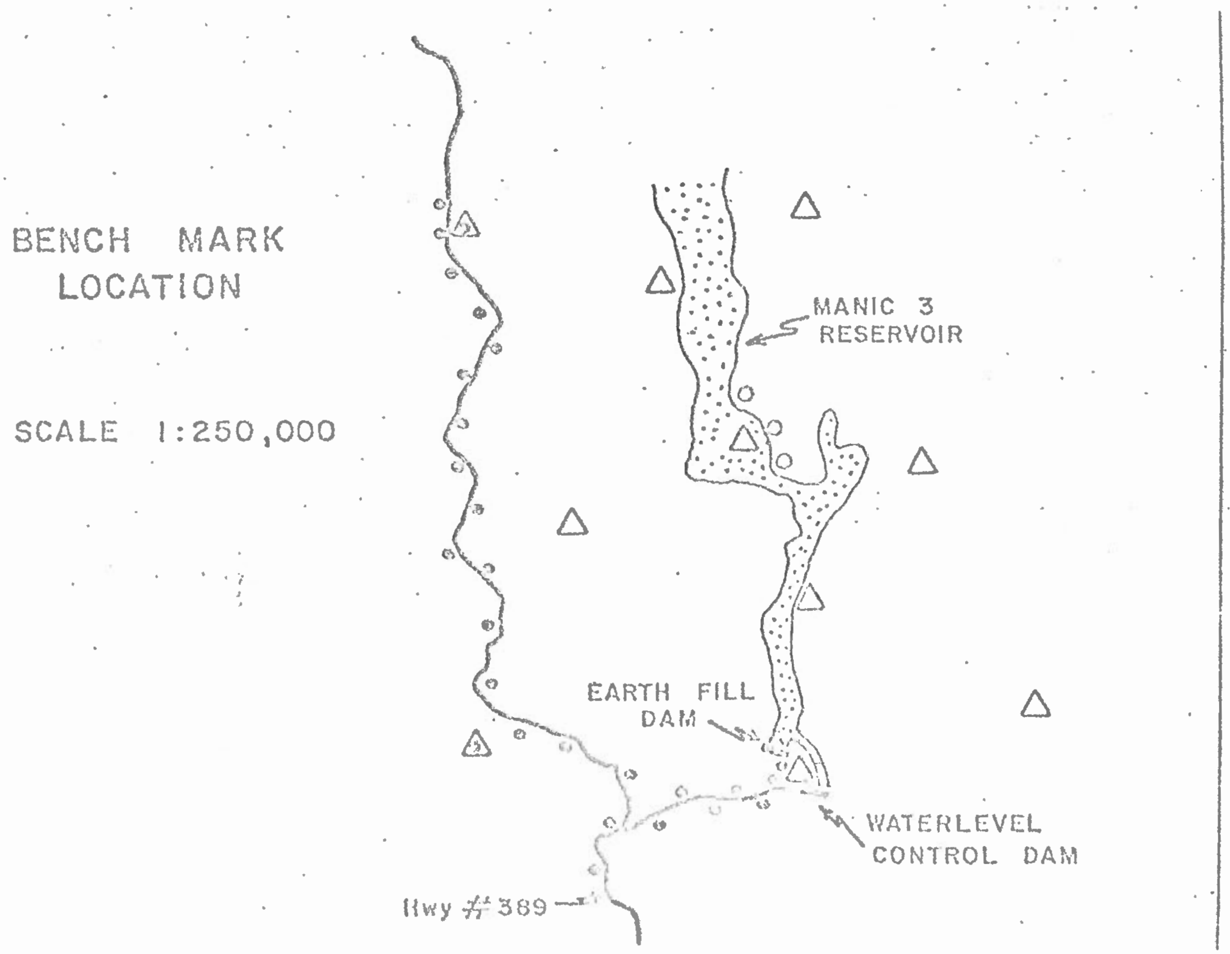
Items 2 and 3 above are not considered part of the network for crustal deformation studies.

2.3 Vertical Control Requirements

Precise elevations at all horizontal control stations would have been most desirable. The lack of access roads and heavy forest cover eliminated any possibility of reaching the stations in the eastern portion and most of the central portion of the network. A close examination of the latest aerial photographs showed that only stations TAQUET and POSTE MICOUA were accessible by vehicle and only stations VALLANT and CENTRALE were within reasonable walking distance of ground transportation.

It was decided that the existing precise level line along Highway #389 would be re-run and densified in the north/south direction, extending at least two existing bench marks beyond the north and south limits of the Strain Polygon. In the east/west direction, bench marks would be established approximately every two kilometres along the dam access road and in the vicinity of the dam.

FIGURE 3



Precise elevations would be established at a maximum of 4, and a minimum of 2, horizontal control stations. Figure 3 shows the approximate locations of the bench marks with respect to the first-order horizontal control stations.

2.4 Personnel

The Labrador-Northern Québec scale control party would be responsible for all phases of the Manic (Surveys and Mapping) project except the Precise Vertical Control, the Astronomic observations and the Mekometer measurements. The crew would consist of: 2 permanent staff from Geodetic Survey, 10 students, 2 aircrew and 2 labourers.

There was very little construction associated with the Labrador-Northern Québec scale control consequently no spearate construction crew was planned. Rather the emphasis was placed on hiring people that could use the measuring instruments, record observations and do the station preparation when necessary. Because of the extensive cutting and tower building at Manic, two construction personnel would be added.

The Primary Horizontal and Vertical Control Sections and the Supplementary Control Section of the Geodetic Survey would provide supervisory and other personnel to do the precise levelling (1 permanent, 6 casual), astronomic observations (1 permanent, 1 casual) and Mekometer measurements (1 permanent, 2 casual).

2.5 Lambert Tower Tests

The Geodetic Survey first tested the Lambert tower on field operations during the 1975 field season, *(McDowell, 1975; Swanson, 1975)*. The tests showed clearly that it was possible to measure angles and distances with first-order accuracy from the tower. As a sequel to the tests it remained for the towers to be tested extensively in a production situation. The Manic project appeared to have all the desirable features for continuing the investigation. Of particular interest was the prospect of examining a unique feature of the Lambert tower, that of slinging the assembled unit and securing it while being held erect on the station by a helicopter.

III - FIELD OPERATIONS

During the last week in June, four men left L'Anse-au-Claire, Labrador, en route to Ottawa/Hull where they loaded tower parts and other equipment for the Manic project. A fifth man joined the party in Baie-Comeau.

The advance party organized the equipment and tower storage areas at the Manic camp, began station preparation at TAQUET and POSTE MICOUA and made preparations for the later arrival of the remainder of the crew.

Eight men plus equipment and instruments arrived at Baie-Comeau by air from Schefferville on July 13. They were met by the advance party with Dept. vehicles for transport to Manic 3. The helicopter and crew also arrived at Manic on the 13th.

3.1 Field Reconnaissance

The hills selected from contour maps at the planning stage were examined closely to determine their suitability for stations. In making a final choice of hill and site, the governing factors were:

1) The verification of intervisibility between adjacent stations,

2) The size of the trees and the density of the tree cover that had to be removed,

3) The condition (non-fractured) and accessibility of bedrock, and to a limited extent,

4) The accessibility by motor vehicle or helicopter.

3.2 Station Preparation

This was by far the most arduous and time consuming phase of the project. Before equipment for tower construction and monument installation could be moved in, it was necessary to do extensive clearing of trees and underbrush at 7 sites, considerable clearing at 3 other sites and a minimal amount at three others.

To protect rotor blades and floats, helicopter pads were built at 9 stations.

3.21 Tower Construction

Observing towers were used at 9 stations. Tower heights were chosen to give at least 5 metres clearance above local trees and the intervening terrain. The choice of tower type was based on conditions at the site or on the distance that the tower material had to be carried by helicopter.

Lambert towers were used where bedrock was near the surface, where there were no space limitations and where height requirements did not exceed 18 metres.

The use of the Bilby tower was not restricted by conditions at any site but since the Bilby/Lambert weight ratio is approximately 3 (for an 18 metre tower), it was economically advantageous to keep the Bilby towers as near as possible to ground transportation.

A wooden tower was used at station ILE MANIC as the height required was only 8 metres and the construction time element was considerably less compared to that of moving a tower from another station where obsevations were completed.

3.22 Slinging Tower Material by Helicopter

Eight towers were slung by helicopter into station sites. The Bilby tower parts were bundled together without assembly, the wooden tower was partly assembled before transporting and the Lambert towers were slung as single assembled units.

The hazards involved with spotting the Lambert tower over the station and securing it as it was being held by the helicopter, were a source of much concern. A lot of planning, experimentation and fabrication were necessary to develop techniques, procedures and special equipment to accomplish this task in a safe, efficient manner. A detailed description of the slinging operations is included in *(Swanson, 1976)*.

3.23 Plumbing the Towers

Special care was taken to ensure that plumbing was precise and frequent. Optical plummets were used for this purpose. Plumbing was checked each day until it was certain that there was no gradual movement. Subsequent plumbing was less frequent but never less than every second observing period.

To verify their accuracy, the plummets were compared against each other by plumbing two Bilby towers then testing the results against the line intersection method using T3 theodolites. In both cases there was no substantial variation in centering between the plummets or T3's.

Special equipment and techniques were developed in order that an observation crew of two could plumb the Lambert tower rapidly and accurately with two optical plummets offset from the station. Details are available in *(Swanson, 1976)*.

3.24 Monumentation

At all stations except VALLANT, bronze tablets were cemented into drill holes in bedrock for station markers. At most stations it was necessary to clear away soil to a depth of a few centimetres to a metre.

At VALLANT, bedrock was struck at a depth of 3 metres from the surface. A metal cylindrical form 60 cm in diameter, 3 metres in depth was used to hold a poured concrete monument. Reinforcing rods, set into drill holes, attached the concrete to the bedrock. A bronze tablet was set in the upper surface as a station marker.

Preparation of the 10 main stations was completed on August 10th. The MEKO stations, two traverse stations and one secondary station were prepared while observation parties were at work on the main network. Two existing stations, NICHOLAS and MANICOUAGAN, near Baie-Comeau were prepared after measurements in the main network were completed.

IV - OBSERVING

All direction and distance measurements and the astronomical observations were taken during a 3 week period beginning August 13th. Precise levelling was done during a 4 week period beginning July 29th The following is a summary of the angle and distance measurements taken in the Strain Polygon:

4.1 Directions and Distances

With one minor exception, Geodimeter and T3 measurements conformed to first-order specifications as laid down in *(S&M Branch, 1973)*. The final directions at Guerite on the lines to POSTE MICOUA and CENTRALE

Measurement Type	Instrument	Number of Measurements
Distance	Geodimeter Model 8	17
	Geodimeter Model 6BL	13
	Mekometer ME3000	5
Direction	Wild T3	56
Laplace (Azimuth, Latitude and Longitude)	Wild T4	1

comprise only 18 (vs 24) sets as windy conditions at that station slowed the observations to the extent that the third measurement was spread over the same period as measurements 3 and 4 at the other stations. As such, the effect of the meteorlogical conditions on each direction should be the same. The *a priori* standard deviations of these lines have been increased according to the number of sets.

The first two angle measurements at ONGLET on the directions to VALLANT, MOYEU and TAQUET were rejected because the instrument support pipe was not adjusted properly. Strong winds caused the pipe to vibrate against the outer tower, consequently it was extremely difficult to point the instrument properly. Two additional measurements were taken, at all stations involved, to replace the first and second.

4.2 Mekometer Measurements

Four measurements were taken on each of the Mekometer lines. A measurement consisted of 4 determinations with the instrument at one end of the line and 4 determinations with instrument at the other end. The Mekometer was moved from one end to the other for successive determinations.

The Mekometer has an inherent error of 0.2 mm ± 3 ppm when used on standard baselines. However, when ground points are employed, centering error reduces the quality of the observations. Assuming a 1 mm centering error, an estimated accuracy would be in the order of 1.5 mm ± 3 ppm *(Fenton, 1976)*. This is the criterion that was specified for the internal consistency of each measurement.

It should be noted that the Mekometer measurements at ILE MANIC were not taken from the tower as the lines were open at ground level.

4.3 Astronomical Obsevations

Standard Geodetic Survey of Canada specifications, procedures and field checks for first-order determinations were followed.

4.4 Precise Levels

Check lines run	1 (63.9 km)
New bench marks established	11
Kms of levelling	80.05
Gravity stations tied in	3
Horizontal control stations tied in	2

Measurements, procedures and field checks conformed to standard practice for Special Order levelling as given in *(S&M Branch, 1973)*.

4.5 Supplementary Measurements

In addition to the foregoing measurements, a minimum of 6 simultaneous reciprocal zenith distances were measured at each end of each line. Ten distances and 14 directions were measured to connect the Strain Polygon to existing mapping control in the area and to the existing first-order triangulation on the north shore of the St. Lawrence River.

V - FIELD COMPUTATIONS

The computations done in the field are those associated with data reduction and the detection of sub-standard measurements and blunders. Procedures, formulae and forms involved are explained in detail in Part 7 and Appendix E of *(Geodetic Survey of Canada, 1974)*.

For the horizontal measurements, a summary of triangle misclosures and angle vs length consistency checks is given in Appendix A.

VI - REDUCTION AND HANDLING OF FIELD RETURNS

Procedures for the above, applicable to direction and distance measurements are clearly explained in a set of instructions entitled "Procedures for Handling Field Returns". This is an unpublished document written for use in the Primary Horizontal Control Section of the Geodetic Survey. It deals with the processing of each type of measurement from the raw field data stage to its entry on a computer card as a single observation.

Three computer programs, LEVELOB *(Peterson, 1970)*, STAADJ *(Beattie, 1973)* and SLRED2 *(Beattie, 1972)* are used to produce a deck of computer cards that contains directions and sea-level distances. A fourth program, SIGMA *(Beattie, 1976)* adds *a priori* standard deviations and observation group identifiers. A list of directions, sea-level distances and *a priori* standard deviations is shown in Appendix B.

A priori standard deviations for the Geodimeters, T3 and T4 theodolites listed Section 2.2 (Network Design) were also used for purposes of adjustment. Where short lines were involved, a factor of σ_c = 0.2 cm was added for uncertainty in centering.

For the Mekometer, the *a priori* standard deviations were determined from the following:

$$\sigma = \sqrt{(0.01)^2 + (3L\ 10^{-4})^2} \qquad \text{cm}$$

$$\sigma_c = 0.1 \text{ cm}$$

Astronomical observations and precise levels are similarly reduced by computer programs. The final astronomical azimuth, latitude and longitude are included in the adjustment input deck with the directions and distances.

VII - ADJUSTMENT OF OBSERVATIONS

7.1 <u>All Data Included</u>

Two separate "free" adjustments of the observed material were carried out. The first included all the observations in the Strain Polygon, the connecting traverse to the existing first-order control at Baie-Comeau and the connections to the existing lower-order stations in the vicinity of the Strain Polygon. The published coordinates of the existing stations NICHOLAS and MANICOUAGAN were held fixed.

An examination of the standardized corrections (Appendix B) shows that all the measurements taken are well within the Tau rejection value

(3.727) for a confidence level of 99%. Measurements taking the largest standardized correction and the corresponding residuals are as follows:

Standardized Correction	Residual	ppm	Line	Type of Measurements
2.765	+1.207 secs	-	MOYEU-ILE MANIC	Direction
2.534	-1.097 secs	-	TAQUET-VALLANT	Direction
2.379	-0.035 mtrs	6.4	EVASE-ILE MANIC	Distance
2.359	+0.036 mtrs	2.3	TAQUET-GUERITE	Distance
2.241	-0.060 secs	-	VALLANT-ONGLET	Direction
2.219	-0.034 mtrs	5.5	TAQUET-MOYEU	Distance
2.142	+0.934 secs	-	TAQUET-MOYEU	Direction

An examination of the angle-length test ratios in the field check results (Appendix A) shows that it was apparent in the field that there was considerable disagreement between angles and lengths involving the above stations. The failure rate in three triangles exceeds the allowable 33% but the overall average is well below that at 24%.

The weather at the time some of the above measurements were taken was very hot. Consequently the signal lights were large and moving. This condition doesn't necessarily produce poor results but observers without a lot of experience sometime have difficulty pointing consistently on that type of target. Some reobservations were done in the triangle TAQUET-VALLANT-MOYEU under more stable conditions and the results were more favourable. However, a few additional measurements are not very effective in drawing the means toward the better result when all measurements are used.

7.2 Strain Polygon Only

Only the measurements in the Strain Polygon were entered in the second adjustment. The coordinates for POSTE MICOUA, as determined in the first adjustment, were held fixed and orientation was provided by the astronomic azimuth from POSTE MICOUA to TAQUET.

This adjustment shows a variance ratio (variance after adjustment/

a priori variance) of 0.972 and a range of relative accuracies (95% C.R.) from 13 to 17 ppm. The most notable feature of both relative and point ellipses is the low ratio of minor axis/major axis. This suggests that each line is better determined in length than azimuth, *(Junkins, 1976)*. To substantiate this assumption, a second adjustment of the same data was made with only the standard deviation of the astronomical azimuth changed from 1".131 to 0".1. As a result, the component of the error ellipse perpendicular to the line was reduced radically while the component in the direction of the line remained unchanged.

7.3 Lengths Only

An adjustment of lengths only was run to ascertain the contribution of the angle measurements. A lack of significant change in the relative error ellipses suggests that the weakness in orientation is not a result of the azimuth being poorly carried through the net by weak angle measurement but rather that distance determination by Geodimeter is more dominant in forming the shapes of the triangles, *(Junkins, 1976)*.

This adjustment also points out a geometric weakness in the network which allows the positions of the MEKO stations and ILE MANIC to shift 4 cms with respect to the adjacent stations when the angles are removed.

VIII - CONCLUSIONS AND RECOMMENDATIONS

The network is a very rigid structure, with the major axes of the relative error ellipses reflecting the accuracy of the azimuth of the lines, while the minor axes reflect the accuracy of the length of lines. For the purpose of analyzing displacements in future crustal deformation studies, a 95% level of significance should be based on the factor 2.45 x (the component of the error ellipse in the direction of the line.)

The present statistical analysis indicates that by geodetic methods it would be possible to detect horizontal crustal deformations in the order of 3 cms in the main network and 1 cm on the Mekometer lengths. A 1 cm deformation in the vertical appears well within the range of motion that could be detected by spirit levels. It is possible that half that amount (5 mm) would be noticable.

These conclusions are not indisputable. They are based on standard deviations and confidence regions using the adjusted values of the measured data. It is reasonable to assume that the repetition of all the measurements would produce the same result if there were no crustal deformations but until this is done, there is no proof that it is so. From this point of view it is extremely important to determine the "repeatability" of the measurements while the time lapse is short and crustal deformations are unlikely to add complications.

The reobservation program should include measurements to strengthen the determination of ILE MANIC and the MEKO stations with respect to the main scheme. With a small amount of line clearing at MEKO 3, lines to EVASE, GUERITE and MOYEU could be measured. At MEKO 1, lines could be opened to GUERITE and MOYEU. A connection between VALLANT and ILE MANIC would add strength to the network. Unfortunately, an extra station, tower and extensive clearing would be required as ILE MANIC is well below the steep banks of the river.

The reobservations should not be entrusted to inexperienced observers or done hurriedly. The measurements should be taken only under favourable weather conditions, every precaution should be taken to ensure that the meteorlogical samples are as representative as possible, of the conditions along the line, and that the towers are plumb.

It was again apparent that first-order measurements can be taken from the Lambert tower. It can indeed be transported and erected, as an assembled unit, by helicopter. This, however, is a hazardous operation. Those planning such an operation should be well prepared and the pilot must have extensive slinging experience. Some components of the tower should be changed to better suit the observer and decrease the time required for fine adjustment. Discussion of these deficiencies and recommendations for improvement are covered in *(Swanson, 1976)*.

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APPENDIX A
SUMMARY OF FIELD CHECKS

Triangle	Misclosures	Angle-Length Test Ratio 1	Ratio 2	Ratio 3	Failure Rate (33% allowed)
Taquet-Onglet Moyeu	+0.21	+0.814	+0.619	-0.379	0.0
Taquet-Moyeu Vallant	-0.36	-0.735	-1.558	-1.106	33
Poste Micoua Taquet-Vallant	-0.48	+0.613	+0.379	-0.244	22
Onglet Moyeu-Vallant	+0.96	-0.003	+0.586	+0.540	17
Vallant Onglet-Evase	-1.77	-0.571	-1.494	-1.106	33
Ile Manic Moyeu-Evase	-1.54	-1.964	-1.887	-0.556	39
Vallant Moyeu-Evase	-0.82	-1.037	-0.687	+0.426	38
Ile Manic Guerite-Evase	-0.50	-0.835	-1.484	-0.611	38
Miquelon Guerite-Evase	+0.71	-0.011	+0.174	+0.144	33
Vallant Guerite-Evase	-0.40	-0.417	-0.050	+0.525	30
Miquelon Guerite-Centrale	-0.96	-0.209	-0.027	+0.195	27
Poste Micoua Guerite-Centrale	+0.39	-0.492	-0.048	+0.235	25
Poste Micoua Vallant-Guerite	-1.27	-0.728	-0.060	+0.545	23
Ile Manic Meko 1 - Meko 3	+2.13	-0.602	-1.744	-0.842	24
Meko 1 Meko 2 - Meko 3	+0.84	+0.629	+1.392	+1.288	27
Ile Manic Meko 1 - Meko 2	+3.96	+0.895	+0.090	-1.148	27
Meko 1 Meko 2 - Meko 3	-0.98	+0.099	-0.349	-0.509	25
Poste Micoua Varin-Guerite	-1.63	-0.556	+0.129	+0.614	24

APPENDIX B

MEASURED AND ADJUSTED DATA

OCCUPIED STA.	OBSERVED STA.		DIRECTION	STD DEV	CORR.	ADJ DIRECTION	ST. CORRN
TAQUET	762013	ONGLET	0.000	.603	.337	0 0 0.000	.745
	762012	MOYEU	20 4 25.720	.607	.943	20 4 26.326	2.073
	762014	VALLANT	75 5 6.330	.603	-1.155	75 5 4.838	-2.557
	762019	POSTE MICOUA	93 33 49.700	.601	-.111	93 33 49.252	-.247
MOYEU	762013	ONGLET	0.000	.611	-.314	0 0 0.000	-.687
	762016	EVASE	65 18 43.740	.603	-.134	65 18 43.920	-.297
	762020	ILE MANIC	90 15 24.950	.608	1.258	90 15 26.523	2.762
	762014	VALLANT	137 7 23.890	.604	-.524	137 7 23.681	-1.157
	762011	TAQUET	224 46 20.830	.607	-.279	224 46 20.865	-.613
ONGLET	762016	EVASE	0.000	.603	.061	0 0 0.000	.135
	762014	VALLANT	57 38 15.150	.602	.150	57 38 15.239	.333
	762012	MOYEU	84 32 28.210	.611	.128	84 32 28.277	.279
	762011	TAQUET	109 14 23.270	.603	-.336	109 14 22.873	-.744
VALLANT	762012	MOYEU	0.000	.604	.921	0 0 0.000	2.035
	762013	ONGLET	15 58 25.240	.602	-.963	15 58 23.356	-2.135
	762016	EVASE	61 25 36.150	.602	.298	61 25 35.527	.660
	762015	GUERITE	89 19 6.790	.605	-.140	89 19 5.729	-.308
	762019	POSTE MICOUA	187 19 25.490	.605	.023	187 19 24.592	.051
	762011	TAQUET	322 39 36.620	.603	-.135	322 39 35.564	-.298
GUERITE	762017	MIQUELON	0.000	.604	-.361	0 0 0.000	-.797
	762014	VALLANT	174 5 2.140	.605	-.285	174 5 2.216	-.629
	762020	ILE MANIC	229 46 27.400	.610	.209	229 46 27.970	.457
	762016	EVASE	289 19 31.230	.609	.447	289 19 32.038	.981
EVASE	762017	MIQUELON	0.000	.604	.186	0 0 0.000	.411
	762015	GUERITE	68 8 3.000	.609	-.282	68 8 2.532	-.619
	762014	VALLANT	105 0 3.270	.602	-.483	105 0 2.601	-1.071
	762020	ILE MANIC	125 26 9.180	.609	.809	125 26 9.803	1.773
	762012	MOYEU	151 45 47.840	.603	-.135	151 45 47.519	-.298
	762013	ONGLET	181 54 35.710	.603	-.082	181 54 35.442	-.182
MIQUELCN	762018	CENTRALE	0.000	.605	-.257	0 0 0.000	-.566
	762015	GUERITE	40 54 34.760	.604	-.015	40 54 35.002	-.032
	762016	EVASE	82 6 4.090	.604	.270	82 6 4.617	.597

APPENDIX B

MEASURED AND ADJUSTED DATA

OCCUPIED STA.	OBSERVED STA.		DIRECTION	STD DEV	CORR	ADJ DIRECTION	ST. CORRN
CENTRALE	762019	POSTE MICOUA	0.000	.603	-.188	0 0 0.000	-.416
	762015	GUERITE	82 23 23.320	.610	.031	82 23 23.539	.067
	762017	MIQUELON	157 12 43.430	.605	.159	157 12 43.777	.351
POSTE MICOUA	762011	TAQUET	0.000	.601	-.465	0 0 0.000	-1.032
	762014	VALLANT	26 11 4.120	.605	.164	26 11 4.748	.361
	762015	GUERITE	66 51 56.300	.602	.274	66 51 57.039	.608
	762018	CENTRALE	95 58 24.770	.603	.030	95 58 25.265	.067
ILE MANIC	762021	MEKO 1	0.000	.777	.870	0 0 0.000	1.494
	762022	MEKO 2	82 12 21.950	.933	-.587	82 12 20.493	-.840
	762016	EVASE	101 43 1.930	.609	.445	101 43 1.506	.976
	762023	MEKO 3	121 38 13.090	.741	-.421	121 38 11.799	-.758
	762015	GUERITE	164 51 51.520	.610	-.418	164 51 50.232	-.915
	762012	MOYEU	332 59 22.660	.608	-.028	332 59 21.762	-.062
MEKO 1	762022	MEKO 2	0.000	.741	-.364	0 0 0.000	-.655
	762023	MEKO 3	5 52 13.270	.656	.721	5 52 14.355	1.466
	762020	ILE MANIC	37 9 3.250	.777	-.611	37 9 3.003	-1.049
MEKO 2	762023	MEKO 3	0.000	.893	.170	0 0 0.000	.254
	762020	ILE MANIC	104 32 50.520	.933	1.310	104 32 51.660	1.874
	762021	MEKO 1	165 11 29.280	.741	-.943	165 11 28.166	-1.699
MEKO 3	762020	ILE MANIC	0.000	.741	-.187	0 0 0.000	-.336
	762021	MEKO 1	27 4 58.990	.656	.379	27 4 59.556	.771
	762022	MEKO 2	36 1 17.280	.893	-.431	36 1 17.035	-.645
GUERITE	762017	MIQUELON	0.000	.694	.103	0 0 0.000	.198
	762018	CENTRALE	64 16 4.850	.698	.112	64 16 4.858	.213
	762019	POSTE MICOUA	132 46 13.550	.692	-.212	132 46 13.235	-.409

OCCUPIED STA.	OBSERVED STA.		AZIMUTH	STD DEV	CORR.	LAPLACE	ADJ. AZIMUTH
POSTE MICOUA	762011	TAQUET	359 34 1.190	1.131	.000	-1.171	359 34 2.361

APPENDIX B
MEASURED AND ADJUSTED DATA

OCCUPIED STA.	TO	OBSERVED STA.	DISTANCE	STD DEV	CORR.	PPM	ADJ. DISTANCE	ST. CORRN
TAQUET	762019	POSTE MICOUA	16341.4330	2.201	.0096	.6	16341.4426	.581
TAQUET	762013	ONGLET	10496.3520	1.608	.0079	.8	10496.3599	.660
TAQUET	762014	VALLANT	10258.1900	1.586	-.0217	2.1	10258.1683	-1.825
TAQUET	762015	GUERITE	15725.0340	2.136	.0409	2.6	15725.0749	2.556
MOYEU	762020	ILE MANIC	5764.1380	1.216	.0010	.2	5764.1390	.110
MOYEU	762015	GUERITE	11055.4480	1.661	-.0125	1.1	11055.4355	-1.005
ONGLET	762014	VALLANT	12648.1260	1.818	.0007	.1	12648.1267	.055
VALLANT	762015	GUERITE	7275.3730	1.327	-.0008	.1	7275.3722	-.082
GUERITE	762019	POSTE MICOUA	11052.3670	1.661	-.0026	.2	11052.3644	-.212
GUERITE	762017	MIQUELON	7994.0330	1.366	.0009	.1	7994.0339	.090
GUERITE	762020	ILE MANIC	5350.8460	1.188	-.0082	1.5	5350.8378	-.921
GUERITE	762018	CENTRALE	5424.2540	1.193	-.0027	.5	5424.2513	-.302
GUERITE	762016	EVASE	5672.8100	1.210	.0046	.8	5672.8146	.512
MEKO 1	762023	MEKO 3	2203.4720	1.034	.0043	1.9	2203.4763	.553
TAQUET	762012	MOYEU	6227.3040	1.248	-.0215	3.4	6227.2825	-2.296
MOYEU	762013	ONGLET	5115.3420	2.011	-.0033	.6	5115.3387	-.220
MOYEU	762016	EVASE	10139.3570	2.725	.0104	1.0	10139.3674	.512
MOYEU	762014	VALLANT	8411.1600	2.452	.0154	1.8	8411.1754	.836
ONGLET	762016	EVASE	9254.5980	2.582	-.0275	3.0	9254.5705	-1.421
VALLANT	762016	EVASE	10968.6270	2.863	.0322	2.9	10968.6592	1.499
VALLANT	762019	POSTE MICOUA	7368.3570	2.299	-.0065	.9	7368.3505	-.376
EVASE	762015	GUERITE	5672.8080	2.076	.0066	1.2	5672.8146	.427
EVASE	762020	ILE MANIC	5481.5530	2.053	-.0366	6.7	5481.5164	-2.377
EVASE	762017	MIQUELON	8128.3620	2.409	.0092	1.1	8128.3712	.510
MIQUELON	762018	CENTRALE	7461.5690	2.312	.0063	.8	7461.5753	.364
CENTRALE	762019	POSTE MICOUA	10374.8440	2.763	.0141	1.4	10374.8581	.680
CENTRALE	762020	ILE MANIC	10689.0100	2.816	.0119	1.1	10689.0219	.563
ILE MANIC	762022	MEKO 2	816.4470	.283	-.0017	2.1	816.4453	-.823
ILE MANIC	762021	MEKO 1	1178.3130	.381	.0016	1.3	1178.3146	.545
ILE MANIC	762023	MEKO 3	1343.7950	.427	.0005	.4	1343.7955	.157
MEKO 1	762022	MEKO 2	1339.4310	.426	-.0010	.8	1339.4300	-.315
MEKO 2	762023	MEKO 3	881.7790	.300	.0000	.0	881.7790	.003

APPENDIX C

STANDARD ERROR ELLIPSES

Ellipses Based On The A Priori Variance Factor = 1.000

STATION FROM	STATION TO	DIST (KM)	MEAN AZ (DEG)	AZ OF MAJ AXIS	SEMI MAJ AXIS (M)	SEMI MIN AXIS (M)	RATIO MIN/MAJ	AZ SEC	DIST M	DIST PPM
POSTE MICOUA	TAQUET	16.34	179.57	89.57	.090	.015	.17	1.13	.015	.93
	VALLANT	7.37	25.77	117.40	.042	.014	.33	1.17	.014	1.86
	GUERITE	11.05	66.49	157.35	.062	.012	.19	1.16	.012	1.06
	CENTRALE	10.37	95.60	6.99	.060	.016	.27	1.18	.016	1.55
TAQUET	POSTE MICOUA	16.34	179.57	89.57	.090	.015	.17	1.13	.015	.93
	MOYEU	6.23	106.11	15.96	.036	.009	.26	1.19	.009	1.52
	ONGLET	10.50	86.06	175.63	.060	.012	.20	1.18	.012	1.12
	VALLANT	10.26	161.10	70.55	.057	.010	.18	1.15	.010	1.02
	GUERITE	15.73	139.35	49.05	.087	.010	.12	1.15	.010	.65
MOYEU	TAQUET	6.23	106.11	15.96	.036	.009	.26	1.19	.009	1.52
	ONGLET	5.12	61.39	151.32	.030	.012	.38	1.22	.012	2.25
	VALLANT	8.41	18.48	108.28	.047	.011	.22	1.16	.011	1.27
	GUERITE	11.06	157.36	67.21	.062	.009	.14	1.16	.009	.77
	EVASE	10.14	126.72	36.53	.057	.011	.19	1.17	.011	1.07
	ILE MANIC	5.76	151.64	61.79	.033	.009	.27	1.19	.009	1.55
	MEKO 1	4.74	145.16	55.66	.028	.009	.34	1.23	.009	2.00
	MEKO 2	6.08	144.36	54.43	.035	.009	.27	1.19	.009	1.54
ONGLET	TAQUET	10.50	86.06	175.63	.060	.012	.20	1.18	.012	1.12
	MOYEU	5.12	61.39	151.32	.030	.012	.38	1.22	.012	2.25
	VALLANT	12.65	34.47	124.71	.071	.011	.16	1.16	.011	.91
	EVASE	9.25	156.89	66.98	.053	.014	.26	1.17	.014	1.50
VALLANT	POSTE MICOUA	7.37	25.77	117.40	.042	.014	.33	1.17	.014	1.86
	TAQUET	10.26	161.10	70.55	.057	.010	.18	1.15	.010	1.02
	MOYEU	8.41	18.48	108.28	.047	.011	.22	1.16	.011	1.27
	ONGLET	12.65	34.47	124.71	.071	.011	.16	1.16	.011	.91
	GUERITE	7.28	107.82	18.19	.042	.009	.22	1.18	.009	1.28
	EVASE	10.97	79.95	170.09	.062	.011	.17	1.17	.011	.98
	ILE MANIC	6.14	61.75	151.94	.036	.011	.32	1.20	.011	1.85

APPENDIX C

STANDARD ERROR ELLIPSES

Ellipses Based On The A Priori Variance Factor = 1.000

STATION FROM	STATION TO	DIST (KM)	MEAN AZ (DEG)	AZ OF MAJ AXIS	SEMI MAJ AXIS (M)	SEMI MIN AXIS (M)	RATIO MIN/MAJ	AZ SEC	DIST M	DIST PPM
GUERITE	POSTE MICOUA	11.05	66.49	157.35	.062	.012	.19	1.16	.012	1.06
	TAQUET	15.73	139.35	49.05	.087	.010	.12	1.15	.010	.65
	MOYEU	11.06	157.36	67.21	.062	.009	.14	1.16	.009	.77
	VALLANT	7.28	107.82	18.19	.042	.009	.22	1.18	.009	1.28
	EVASE	5.67	43.12	133.32	.033	.008	.23	1.20	.008	1.36
	MIQUELON	7.99	113.81	23.97	.047	.010	.22	1.21	.010	1.31
	CENTRALE	5.42	178.04	87.81	.033	.009	.28	1.25	.009	1.69
	ILE MANIC	5.35	163.54	73.67	.031	.008	.26	1.20	.008	1.52
	MEKO 3	4.47	175.43	85.30	.027	.009	.32	1.23	.009	1.93
EVASE	MOYEU	10.14	126.72	36.53	.057	.011	.19	1.17	.011	1.07
	ONGLET	9.25	156.89	66.98	.053	.014	.26	1.17	.014	1.50
	VALLANT	10.97	79.95	170.09	.062	.011	.17	1.17	.011	.98
	GUERITE	5.67	43.12	133.32	.033	.008	.23	1.20	.008	1.36
	MIQUELON	8.13	155.02	63.91	.048	.014	.29	1.21	.014	1.70
	ILE MANIC	5.48	100.41	10.10	.032	.010	.33	1.21	.010	1.91
	MEKO 2	4.72	103.73	13.38	.028	.011	.39	1.22	.011	2.28
	MEKO 3	4.24	94.22	3.51	.026	.011	.42	1.24	.011	2.56
MIQUELON	GUERITE	7.99	113.81	23.97	.047	.010	.22	1.21	.010	1.31
	EVASE	8.13	155.02	63.91	.048	.014	.29	1.21	.014	1.70
	CENTRALE	7.46	72.90	163.41	.044	.014	.33	1.22	.014	1.93
CENTRALE	POSTE MICOUA	10.37	95.60	6.99	.060	.016	.27	1.18	.016	1.55
	GUERITE	5.42	178.04	87.81	.033	.009	.28	1.25	.009	1.69
	MIQUELON	7.46	72.90	163.41	.044	.014	.33	1.22	.014	1.93
	ILE MANIC	10.69	170.83	80.89	.061	.011	.19	1.18	.011	1.07
ILE MANIC	MOYEU	5.76	151.64	61.79	.033	.009	.27	1.19	.009	1.55
	VALLANT	6.14	61.75	151.94	.036	.011	.32	1.20	.011	1.85
	GUERITE	5.35	163.54	73.67	.031	.008	.26	1.20	.008	1.52

APPENDIX C

STANDARD ERROR ELLIPSES

Ellipses Based On The A Priori Variance Factor = 1.000

STATION FROM	STATION TO	DIST (KM)	MEAN AZ (DEG)	AZ OF MAJ AXIS	SEMI MAJ AXIS (M)	SEMI MIN AXIS (M)	RATIO MIN/MAJ	AZ SEC	DIST M	DIST PPM
ILE MANIC	EVASE	5.48	100.41	10.10	.032	.010	.33	1.21	.010	1.91
	CENTRALE	10.69	170.83	80.89	.061	.011	.19	1.18	.011	1.07
	MEKO 1	1.18	178.66	87.11	.008	.003	.37	1.36	.003	2.48
	MEKO 2	.82	80.87	170.77	.005	.002	.40	1.36	.002	2.65
	MEKO 3	1.34	120.31	31.69	.009	.003	.32	1.34	.003	2.11
MEKO 1	MOYEU	4.74	145.16	55.66	.028	.009	.34	1.23	.009	2.00
	ILE MANIC	1.18	178.66	87.11	.008	.003	.37	1.36	.003	2.48
	MEKO 2	1.34	141.52	51.28	.009	.003	.34	1.36	.003	2.23
	MEKO 3	2.20	147.39	57.38	.014	.003	.25	1.33	.003	1.59
MEKO 2	MOYEU	6.08	144.36	54.43	.035	.009	.27	1.19	.009	1.54
	EVASE	4.72	103.73	13.38	.028	.011	.39	1.22	.011	2.28
	ILE MANIC	.82	80.87	170.77	.005	.002	.40	1.36	.002	2.65
	MEKO 1	1.34	141.52	51.28	.009	.003	.34	1.36	.003	2.23
	MEKO 3	.88	156.33	66.55	.006	.003	.41	1.42	.003	2.84
MEKO 3	GUERITE	4.47	175.43	85.30	.027	.009	.32	1.23	.009	1.93
	EVASE	4.24	94.22	3.51	.026	.011	.42	1.24	.011	2.56
	ILE MANIC	1.34	120.31	31.69	.009	.003	.32	1.34	.003	2.11
	MEKO 1	2.20	147.39	57.38	.014	.003	.25	1.33	.003	1.59
	MEKO 2	.88	156.33	66.55	.006	.003	.41	1.42	.003	2.84