DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

Drytilt Stations on Mauna Loa and Hualalai Volcanoes, Hawaii

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INTRODUCTION

The United States Geological Survey's Hawaiian Volcano Observatory (HVO) has established a network of drytilt stations on Mauna Loa and Hualalai, Hawaii to monitor ground deformation associated with volcanic activity. Drytilt stations were first established on nearby Kilauea Volcano in 1968 and have proven to be of great value in understanding the subsurface behavior of this volcano over the years. HVO extended drytilt coverage to Mauna Loa in 1975 and to Hualalai in 1984.

The drytilt technique was developed in 1968 by D.B. Jackson and T.L. Wright on Kilauea, Hawaii to complement the wet tilt technique that was already in existence. The purpose for the development of the drytilt technique was to broaden the tilt coverage on Kilauea with the recognition that:

1. The expected tilt changes of Hawaiian volcanoes generally far exceed the precision of the wet tilt system and the less precise, but easier to measure, drytilt technique can be used instead.
2. A method was needed that enabled ground tilt to be measured in the daytime (vs at night using wet tilt) and in all but the most inclement weather conditions.

The early drytilt technique consisted of using a Zeiss Ni2 spirit-level instrument and Invar leveling rods to determine the elevation differences of three nails or benchmarks set approximately 100 meters apart in a triangle. In early 1969, HVO obtained a more precise leveling instrument (Wild N-3) and more accurate level rods. This improved instrumentation allowed the triangular array of benchmarks to be shortened to approximately 40 meters apart, therby reducing refraction errors and maximizing measurement accuracy. Currently, a standard HVO drytilt station consists of three benchmarks installed 30 to 40 meters apart and is measured with a Wild Na-2 precision level instrument with a GPM3 micrometer and

3-meter invar level rods. This setup is used for all of the stations installed since 1969, except those on the summit of Mauna Loa.

PURPOSE

The purpose of this report is to identify, describe, and document the drytilt stations on Mauna Loa and Hualalai that are actively measured by HVO as of May, 1987. Many stations have been lost, destroyed, or abandoned over the years and are not included in this report. The drytilt stations in this report are divided into the following geographic areas:

1. Mauna Loa summit
2. Mauna Loa northeast rift zone and north flank
3. Mauna Loa southwest rift zone and east flank
4. Hualalai

Each geographic group has a general station location map followed by a description of the stations in that group. The stations are described in alphabetical order with:

1. The station name with the dates of operation.
2. Previous name (if any).
3. Latitude, longitude, and the quadrangle map of the station.
4. The station data necessary to compute the station equation.
5. The station equation to determine the tilt vector and mag.
6. Brief instructions on how to get to the station.

Also, a map is included showing the station referenced to topographic features around it with an insert showing the orientation of the X, Y, and Z benchmarks.

STATION TILT EQUATIONS

A standard drytilt station consists of 3 benchmarks (X, Y, and Z) located 30 to 40 meters apart (ideally at the apices of an equilateral

triangle). An equation unique to each station is used to determine the change in tilt over a period of time. This equation is derived from the formula (modified from Eaton, 1959):

northward component of tilt

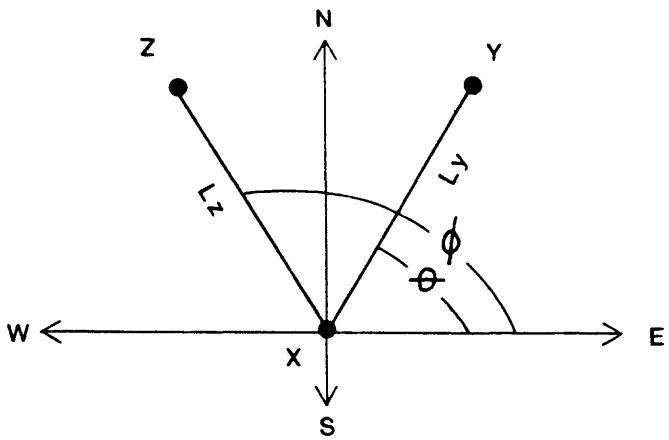
$$\tau\,(N) = \frac{(-\cos\phi)\,(10)\,\delta(y\text{-}x)}{(Ly)\,\sin(\phi-\theta)} - \frac{(\cos\theta)\,(10)\,\delta(x\text{-}z)}{(Lz)\,\sin(\phi-\theta)}$$

eastward component of tilt

$$\tau(E) = \frac{(\sin\phi)\,(10)\,\delta(y\text{-}x)}{(Ly)\,\sin\,(\phi-\theta)} + \frac{(\sin\theta)\,(10)\,\delta(x\text{-}z)}{(Lz)\,\sin(\phi-\theta)}$$

where:

Ly = length of line from X to Y
Lz = length of line from X to Z
θ= angle measured counterclockwise from east to line XY
ϕ= angle measured counterclockwise from east to line XZ
$\delta(y\text{-}x)$ = changes in elevation differences between Y and X
$\delta(x\text{-}z)$ = changes in elevation differences between X and Z



MAUNA LOA DRYTILT NETWORK

In 1975, the first drytilt stations were installed on Mauna Loa. This was part of a larger effort by HVO to establish more ground-deformation monitors due to increased seismicity prior to the eruption on the summit and upper northeast rift zone of Mauna Loa in July, 1975. Most of the stations on Mauna Loa are the standard HVO type (see above), except where the lack of vehicular accessability made it necessary to develop an alternate system (called experimental rods) that was light, portable, and could be transported easily. On the summit of Mauna Loa, 1.5 meter long stainless steel rods were permanently installed over the three benchmarks at each drytilt station. Three precisely graduated 1.5 meter invar strips are attached to these rods before and removed after the station is measured. The horizontal distance between benchmarks was shortened from approximately 40 meters to 30 meters to accomodate the shorter rods (maximum measureable elevation difference between any two benchmarks was reduced from 3.0 meters to 1.5 meters). The elevation differences between the benchmarks for both the standard and experimental rod systems are measured using the three-rod method, described by Yamashita (1981). The Mauna Loa drytilt network has 27 stations.

HUALALAI DRYTILT NETWORK

The first drytilt stations on Hualalai were established in 1984 and currently 9 stations comprise the network. The KANEKII station is included in the Hualalai network due to its geographical position, although it was set up to monitor Mauna Loa. All of the stations are standard drytilt stations (using 3-meter invar rods) and are accessable by a 4-wheel drive vehicle. The three-rod method is used to measure the elevation differences of the three benchmarks.

The Hualalai drytilt stations are located on private land either owned or controlled by the Bishop Estate. Access permission and keys to locked gates can be obtained at their office in the Keauhou Shopping Village.

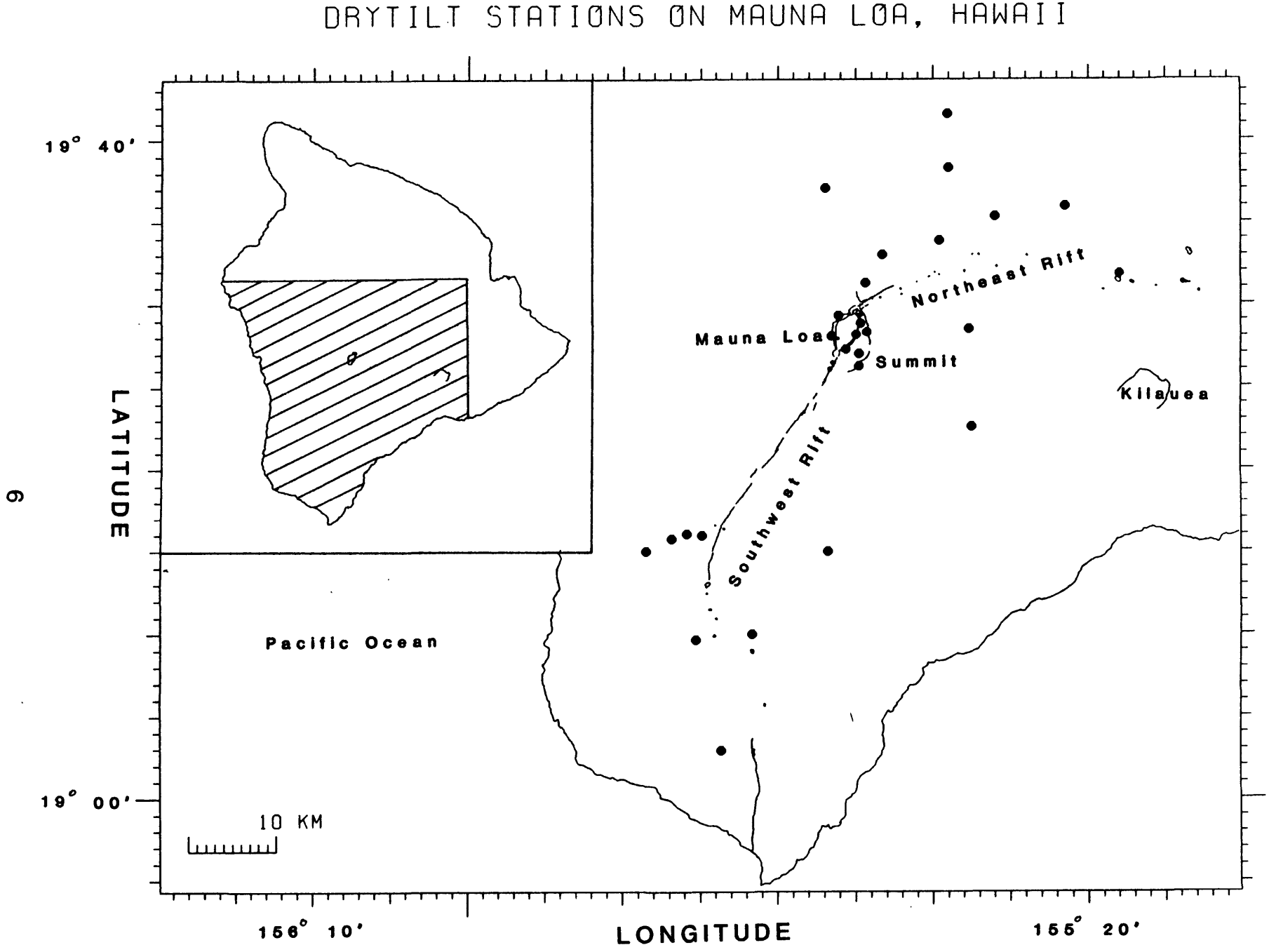
ACKNOWLEDGEMENTS

HVO deformation workers, past and present, are gratefully acknowledged for their efforts in establishing and measuring the drytilt network on Mauna Loa and Hualalai particularly J.C. Forbes, D.B. Jackson, A.T. Okamura, G.S. Puniwai, M.K. Sako, T.L. Wright, and K.M. Yamashita. Special thanks to R.Y. Koyanagi, and T.L. Wright for their constructive critical reviews.

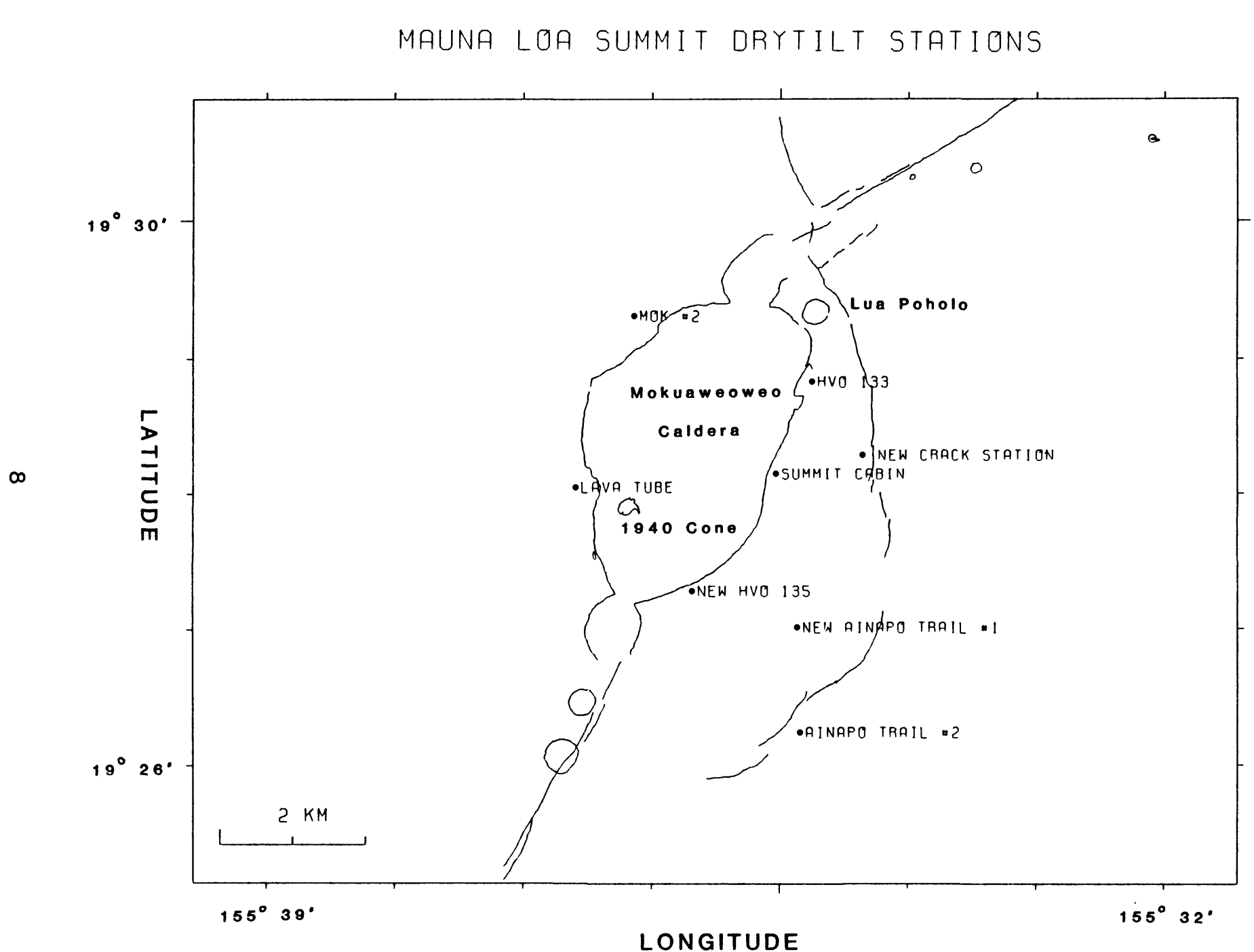
REFERENCES

Eaton, J.P., 1959, A portable water-tube tiltmeter, Bull. Seismol. Soc. Am. 49, pp. 301-316.

Yamashita, K.M., 1981, Dry tilt: a ground deformation monitor as applied to the active volcanoes of Hawaii: U.S. Geological Survey Open-File Report 81-523, 14 p.


DRYTILT STATIONS ON MAUNA LOA, HAWAII
19° 40'
19° 00'
156° 10'
155° 20'
LATITUDE
LONGITUDE
Mauna Loa
Summit
Northeast Rift
Southwest Rift
Kilauea
Pacific Ocean
10 KM

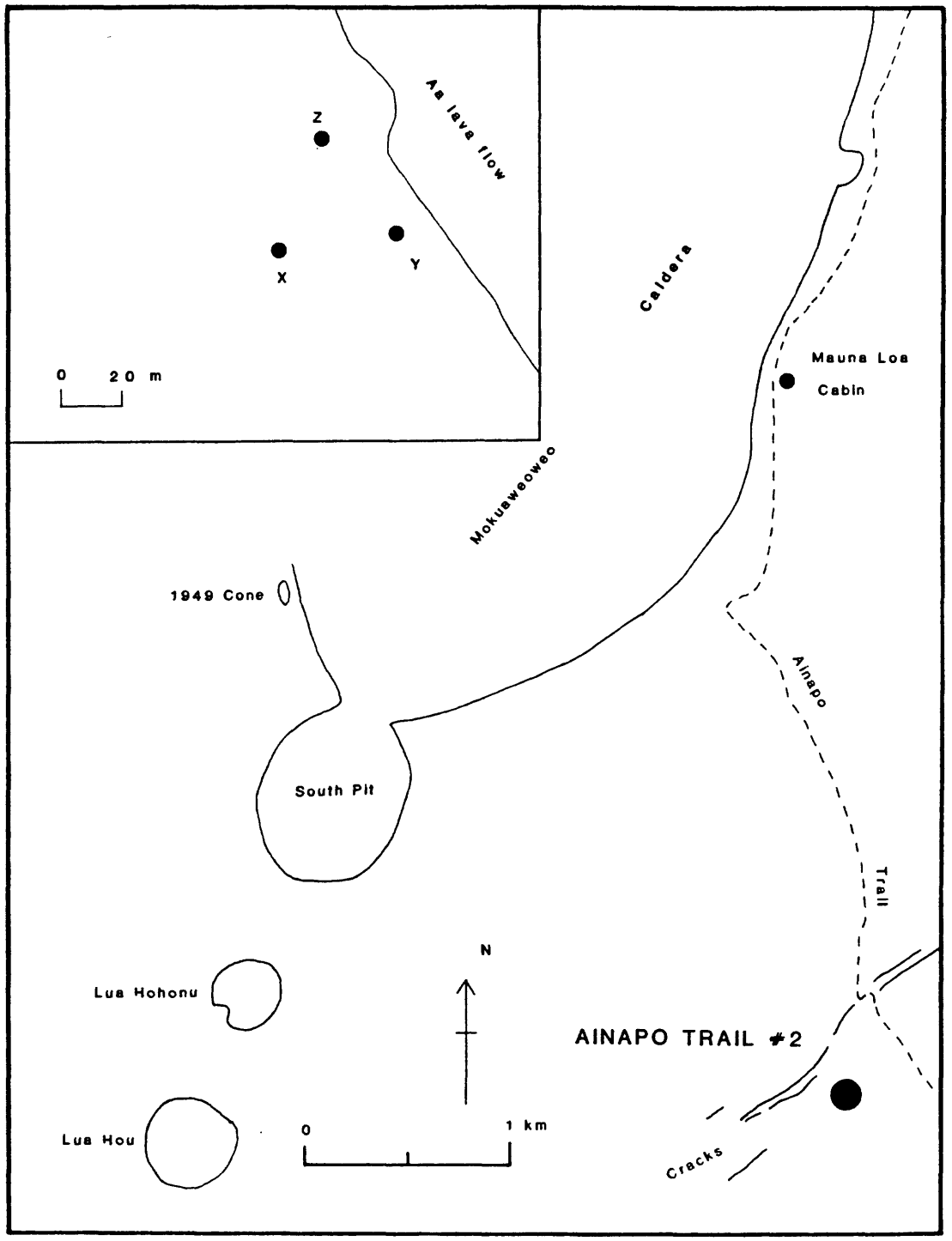
MAUNA LOA SUMMIT DRYTILT STATIONS


MAUNA LØA SUMMIT DRYTILT STATIONS
19° 30'
19° 26'
LATITUDE
155° 39'
155° 32'
LONGITUDE
2 KM
Lua Poholo
•MØK #2
Mokuaweoweo
Caldera
•HVØ 133
•NEW CRACK STATION
•SUMMIT CABIN
•LAVA TUBE
1940 Cone
•NEW HVØ 135
•NEW AINAPØ TRAIL #1
•AINAPØ TRAIL #2

AINAPO TRAIL #2 (9/11/75 to present)

PREVIOUS NAME : None
MAP COORDINATES : N 19 26.24' W155 34.84' Mauna Loa
STATION DATA : Ly = 38.28 m, Lz = 39.26 m, Theta = 12.0, Phi = 68.0
STATION EQUATION : T(n) = -0.118 d(Y-X) - 0.301 d(X-Z)
T(e) = 0.292 d(Y-X) + 0.064 d(X-Z)

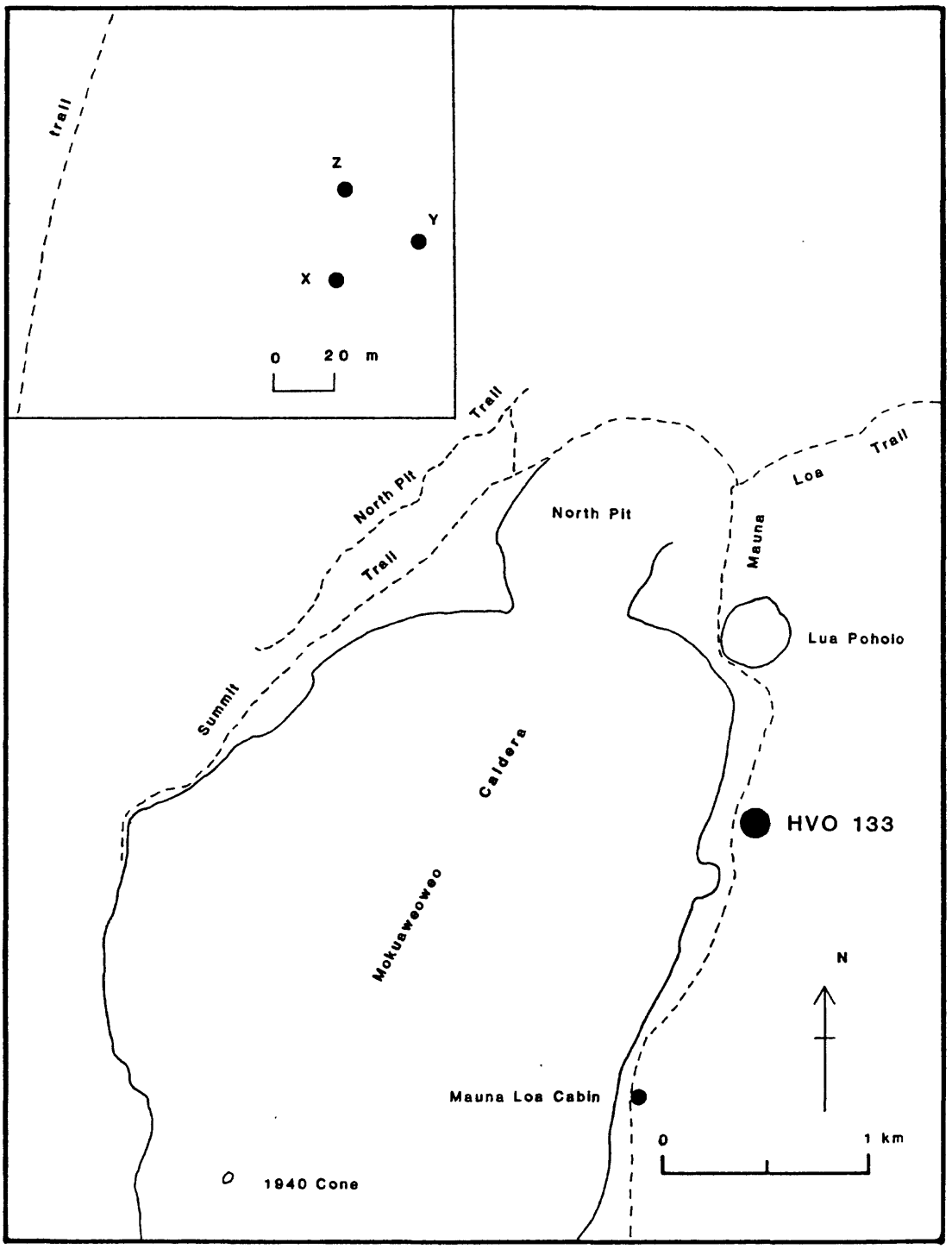
AINAPO TRAIL #2 is located on the southeast side of the summit of Mauna Loa, approximately 3.70 km southeast of the 1949 Cone in Hawaii Volcanoes National Park. The station is at 12,800' elevation, 300 m southwest of the Ainapo trail and 200 m southeast of the outer caldera crack zone. The AINAPO TRAIL #2 station is reached by helicopter and is set up to use 1.5 m invar leveling rods.



HVO 133 (7/16/75 to present)

PREVIOUS NAME : None
MAP COORDINATES : N 19 28.83′ W155 34.75′ Mauna Loa
STATION DATA : Ly = 29.50 m, Lz = 29.50 m, Theta = 25.0, Phi = 85.0
STATION EQUATION : T(n) = −0.034 d(Y-X) − 0.355 d(X-Z)
T(e) = 0.390 d(Y-X) + 0.165 d(X-Z)

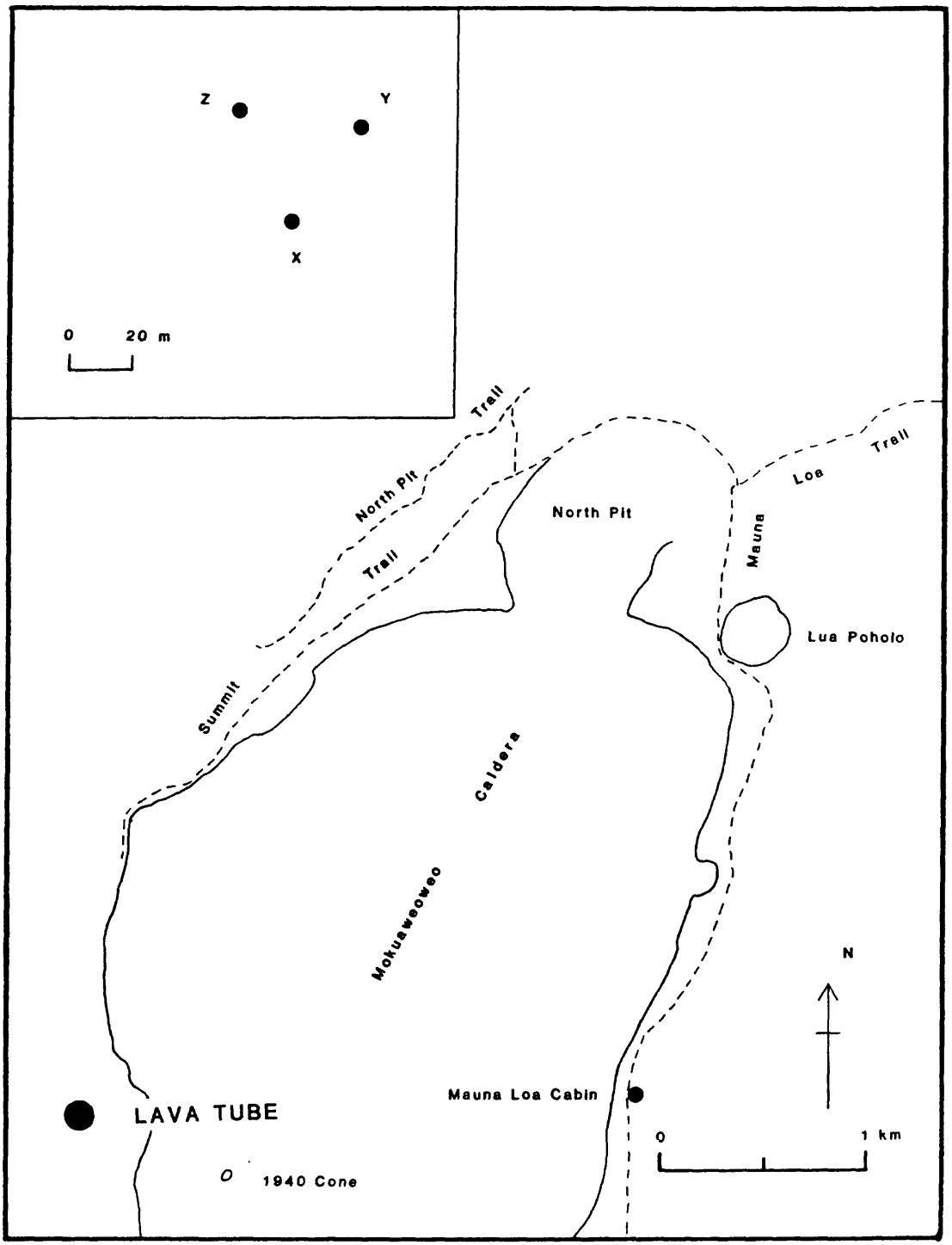
HVO 133 station is located near the northeast edge of Mokuaweoweo caldera, approximately 1.0 km south of Lua Poholo on the summit of Mauna Loa in Hawaii Volcanoes National Park. The station is at 13,230′ elevation, 100 m east of the Mauna Loa trail. The HVO 133 station is reached by helicopter and is set up to use 1.5 m invar leveling rods.



LAVA TUBE (9/11/75 to present)

PREVIOUS NAME : None
MAP COORDINATES : N 19 28.05' W155 36.59' Mauna Loa
STATION DATA : Ly = 38.53 m, Lz = 39.39 m, Theta = 54.0, Phi = 115.0
STATION EQUATION : T(n) = 0.125 d(Y-X) − 0.171 d(X-Z)
T(e) = 0.269 d(Y-X) + 0.235 d(X-Z)

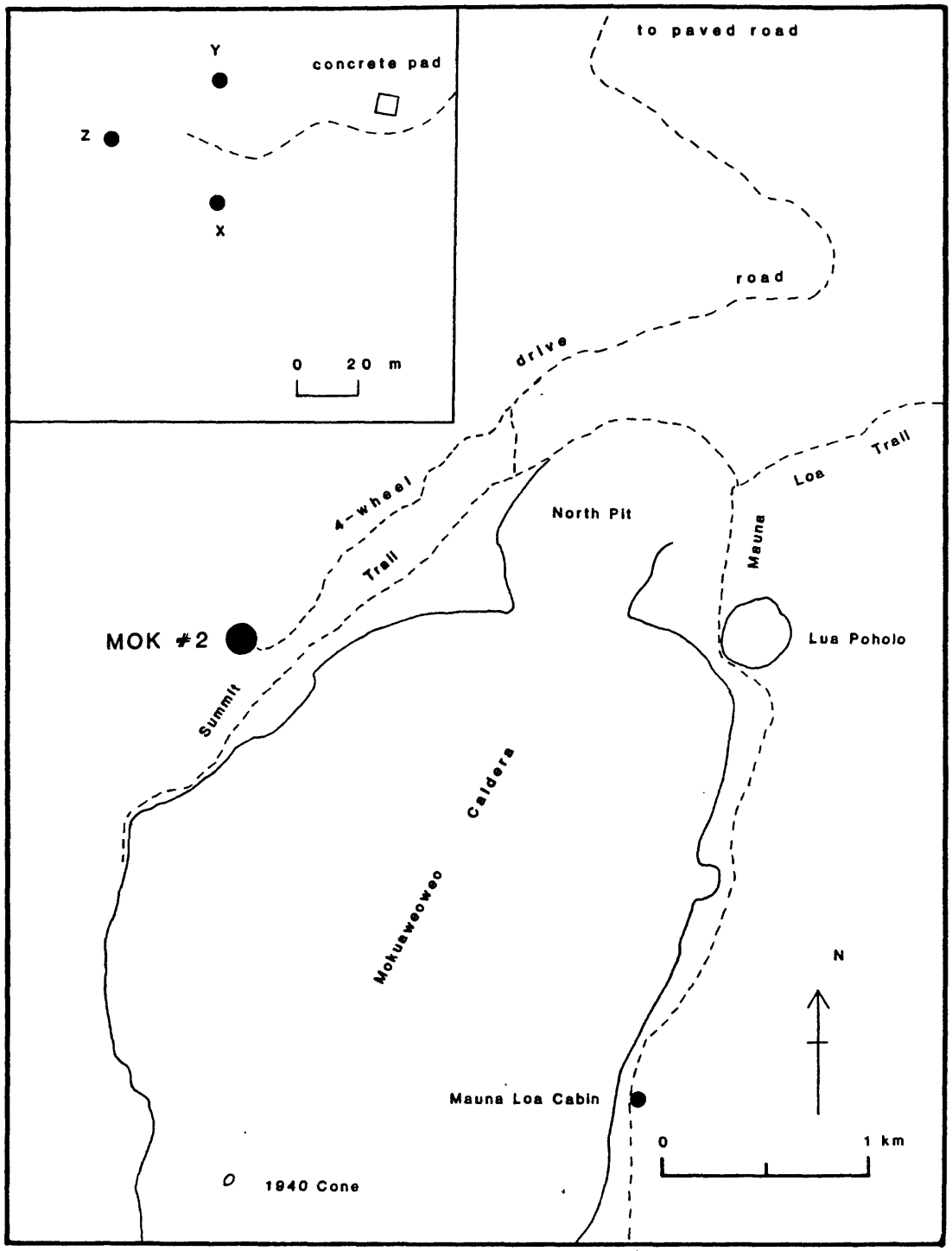
LAVA TUBE station is located near the southwest edge of Mokuaweoweo caldera, approximately 750 m west-northwest of the 1940 Cone on the summit of Mauna Loa in Hawaii Volcanoes National Park. The station is at 13,420' elevation, 200 m southeast of a crack zone. The LAVA TUBE station is reached by helicopter and is set up to use 1.5 m invar leveling rods.



MOK #2 (12/9/76 to present)

PREVIOUS NAME : None
MAP COORDINATES : N 19 29.31' W155 36.14' Mauna Loa
STATION DATA : Ly = 38.90 m, Lz = 40.20 m, Theta = 89.0, Phi = 150.0
STATION EQUATION : T(n) = 0.255 d(Y-X) − 0.005 d(X-Z)
T(e) = 0.147 d(Y-X) + 0.284 d(X-Z)

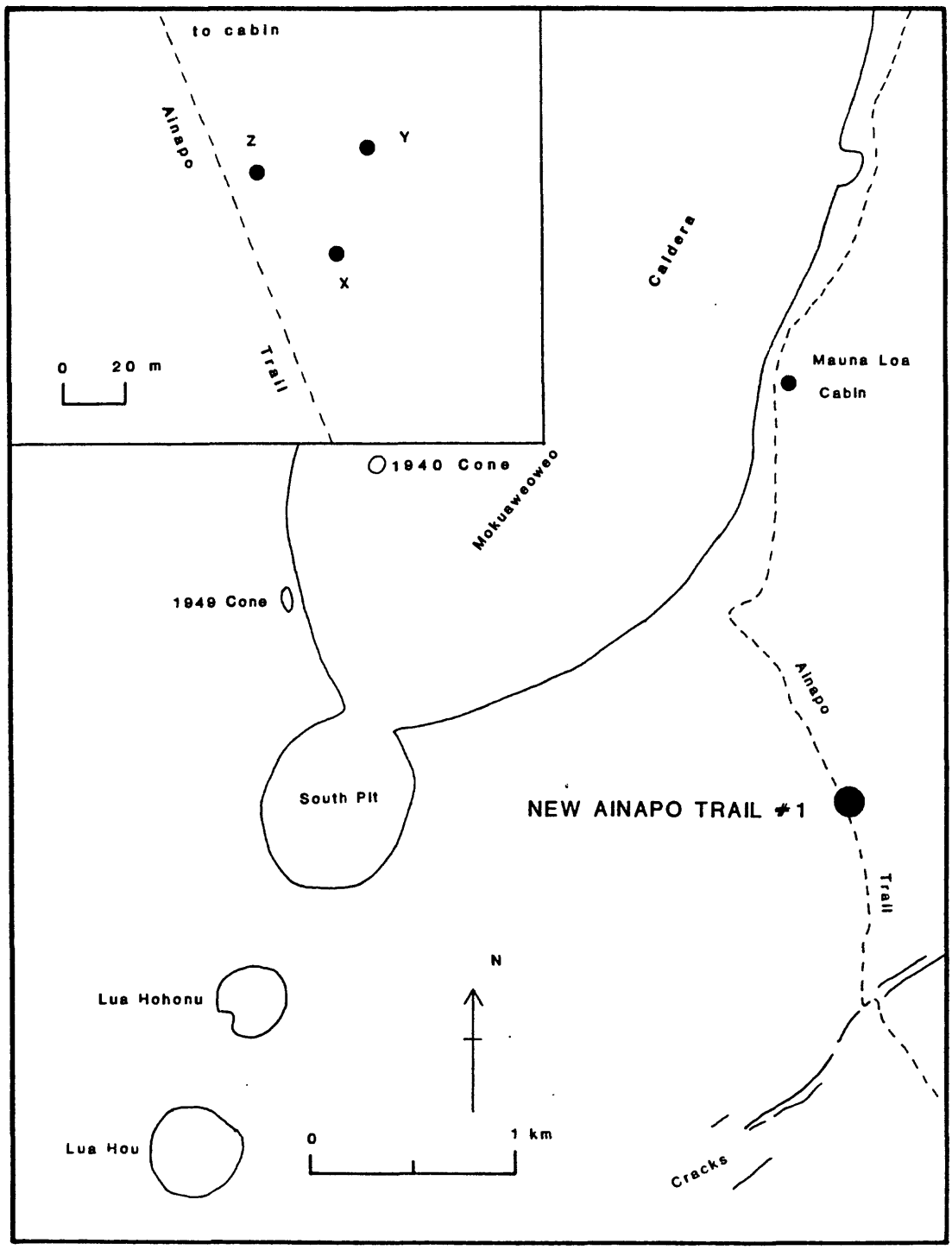
MOK #2 station is located near the northwest edge of Mokuaweoweo caldera, approximately 2.5 km west of Lua Poholo on the summit of Mauna Loa in Hawaii Volcanoes National Park. Drive to the end of the 4-wheel drive dirt road that leads to the summit of Mauna Loa to reach the MOK #2 station.



NEW AINAPO TRAIL #1 (7/13/83 to present)

PREVIOUS NAME : AINAPO TRAIL #1 (7/15/75 to 10/19/82)
MAP COORDINATES : N 19 27.01' W155 34.86' Mauna Loa
STATION DATA : Ly = 35.00 m, Lz = 35.00 m, Theta = 74.0, Phi = 134.0
STATION EQUATION : T(n) = 0.229 d(Y-X) − 0.091 d(X-Z)
T(e) = 0.237 d(Y-X) + 0.317 d(X-Z)

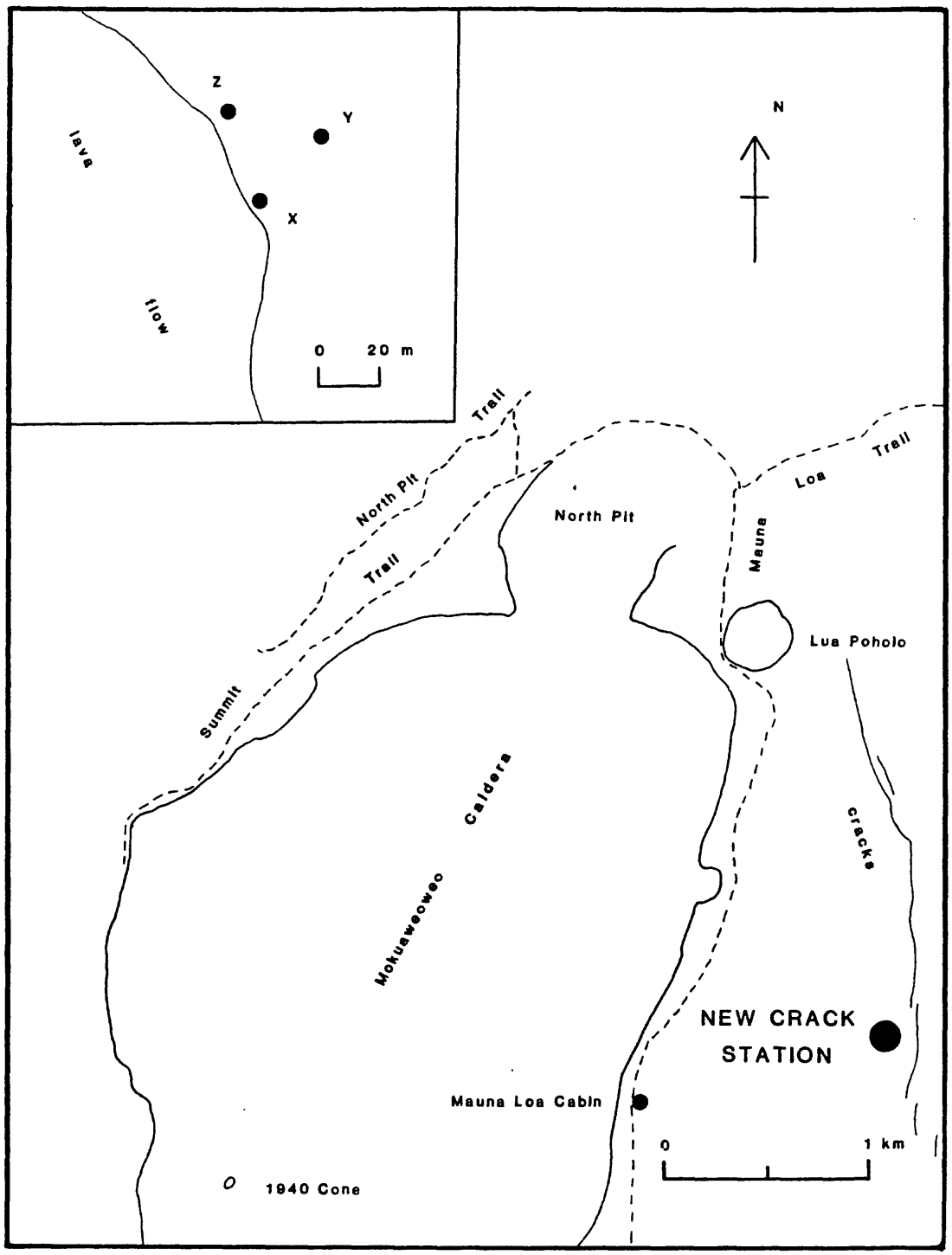
NEW AINAPO TRAIL #1 station is located on the southeast side of the summit of Mauna Loa, approximately 2.85 km southeast of the 1940 Cone in Hawaii Volcanoes National Park. The station is at 13,030' elevation on a flat, black, pahoehoe flow along the Ainapo trail. The NEW AINAPO TRAIL #1 station is reached by helicopter and is set up to use 1.5 m invar leveling rods.



NEW CRACK STATION (4/6/84 to present)

PREVIOUS NAME : CRACK STATION (7/16/75 to 4/6/84)
MAP COORDINATES : N 19 28.29' W155 34.36' Mauna Loa
STATION DATA : Ly = 30.00 m, Lz = 30.00 m, Theta = 48.0, Phi = 108.0
STATION EQUATION : $T(n) = 0.119\, d(Y-X) - 0.258\, d(X-Z)$
$T(e) = 0.366\, d(Y-X) + 0.286\, d(X-Z)$

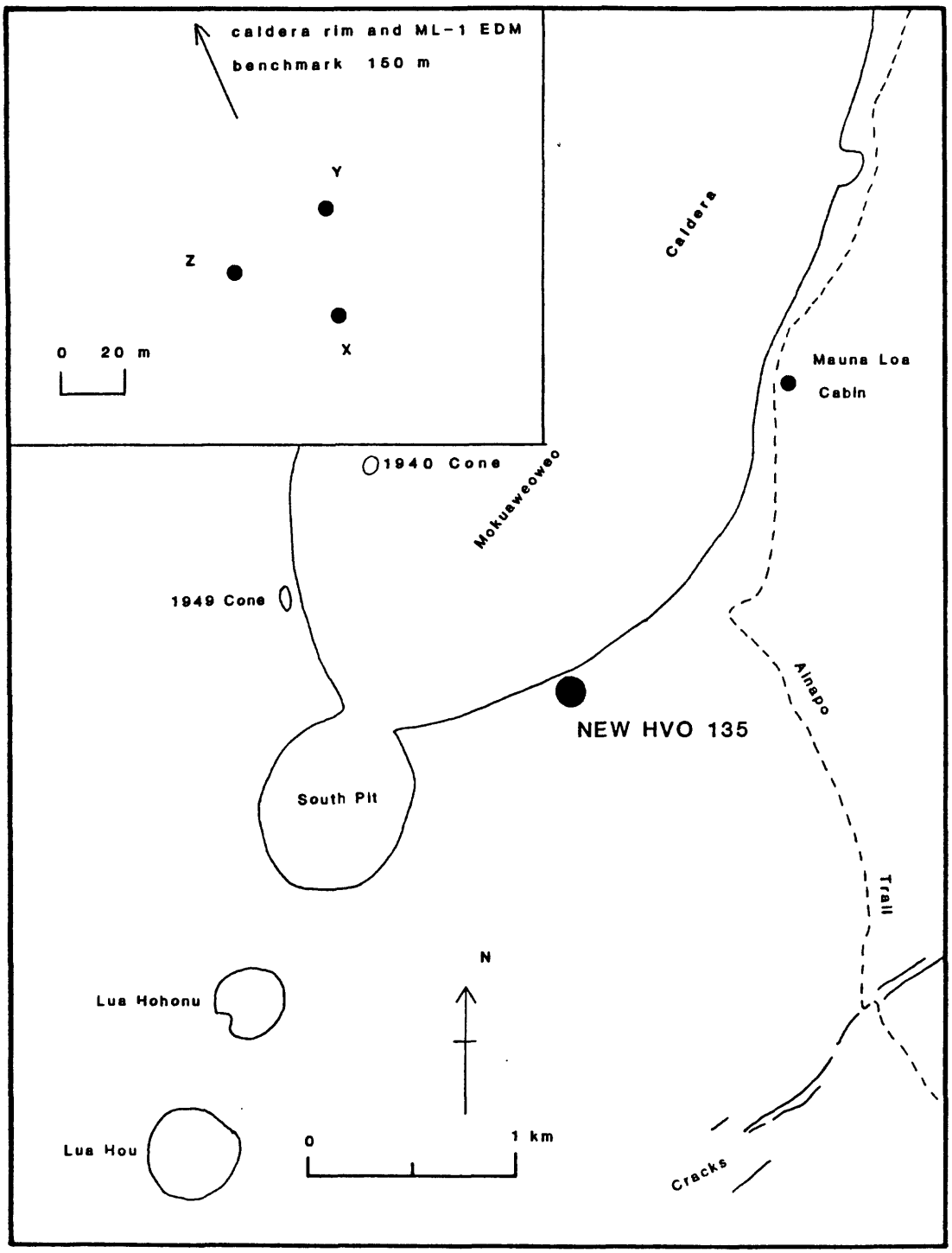
NEW CRACK STATION is located on the east side of the summit of Mauna Loa, approximately 1.1 km east-northeast of the summit cabin in Hawaii Volcanoes National Park. The station is at 13,050' elevation, 100 m west of the outer caldera crack zone. The NEW CRACK STATION is reached by helicopter and is set up to use 1.5 m invar leveling rods.



NEW HVO 135 (7/26/77 to present)

PREVIOUS NAME : OLD HVO 135 (7/15/75 to 6/23/77)
MAP COORDINATES : N 19 27.28' W155 35.68' Mauna Loa
STATION DATA : Ly = 35.00 m, Lz = 35.00 m, Theta = 96.0, Phi = 156.0
STATION EQUATION : T(n) = 0.301 d(Y-X) + 0.034 d(X-Z)
T(e) = 0.134 d(Y-X) + 0.328 d(X-Z)

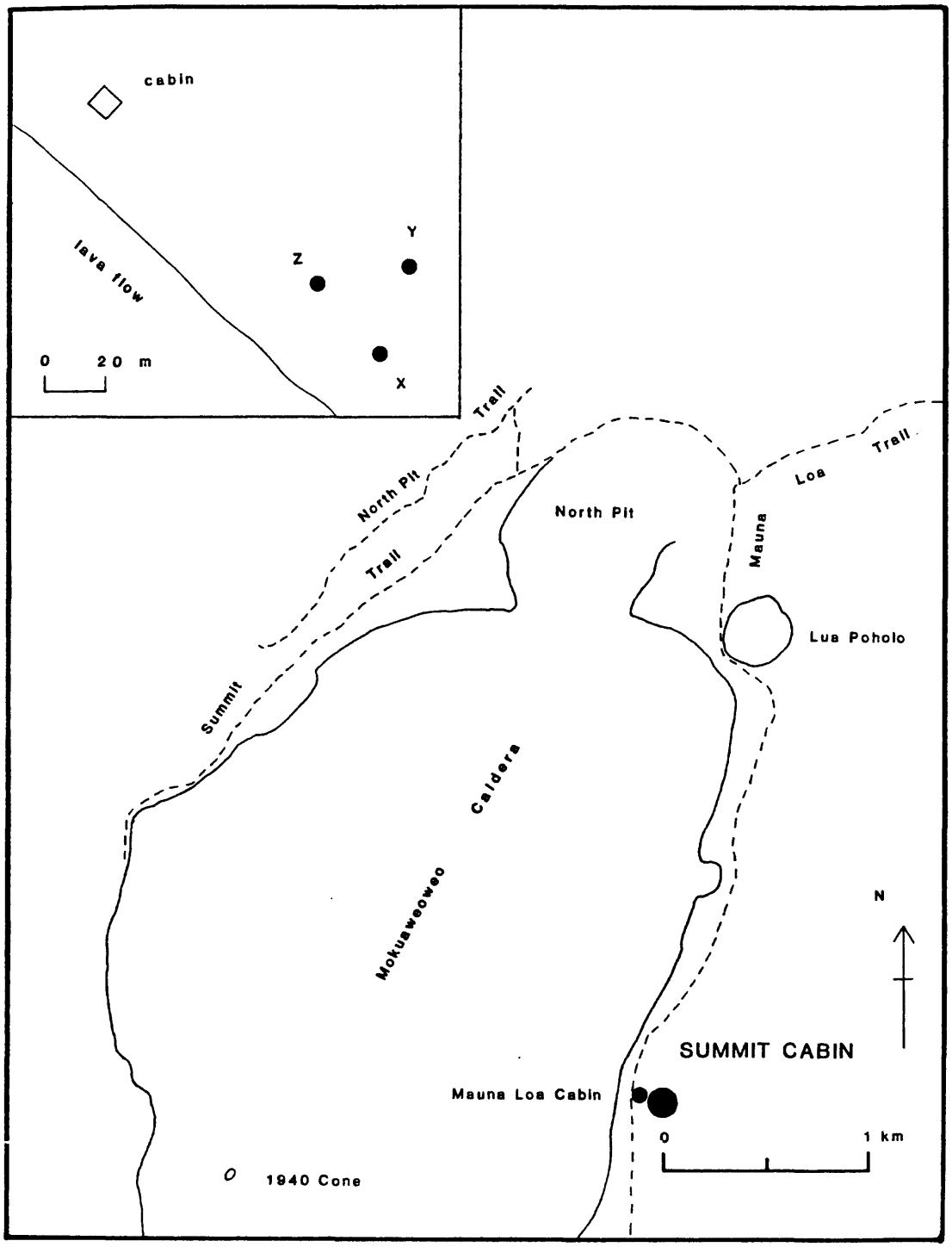
NEW HVO 135 is located on the southern edge of Mokuaweoweo caldera, approximately 1.4 km southeast of the 1940 Cone on the summit of Mauna Loa in Hawaii Volcanoes National Park. The station is at 13,280' elevation, 100 m south of the caldera rim. The NEW HVO 135 station is reached by helicopter and is set up to use 1.5 m invar leveling rods.



SUMMIT CABIN (7/16/75 to present)

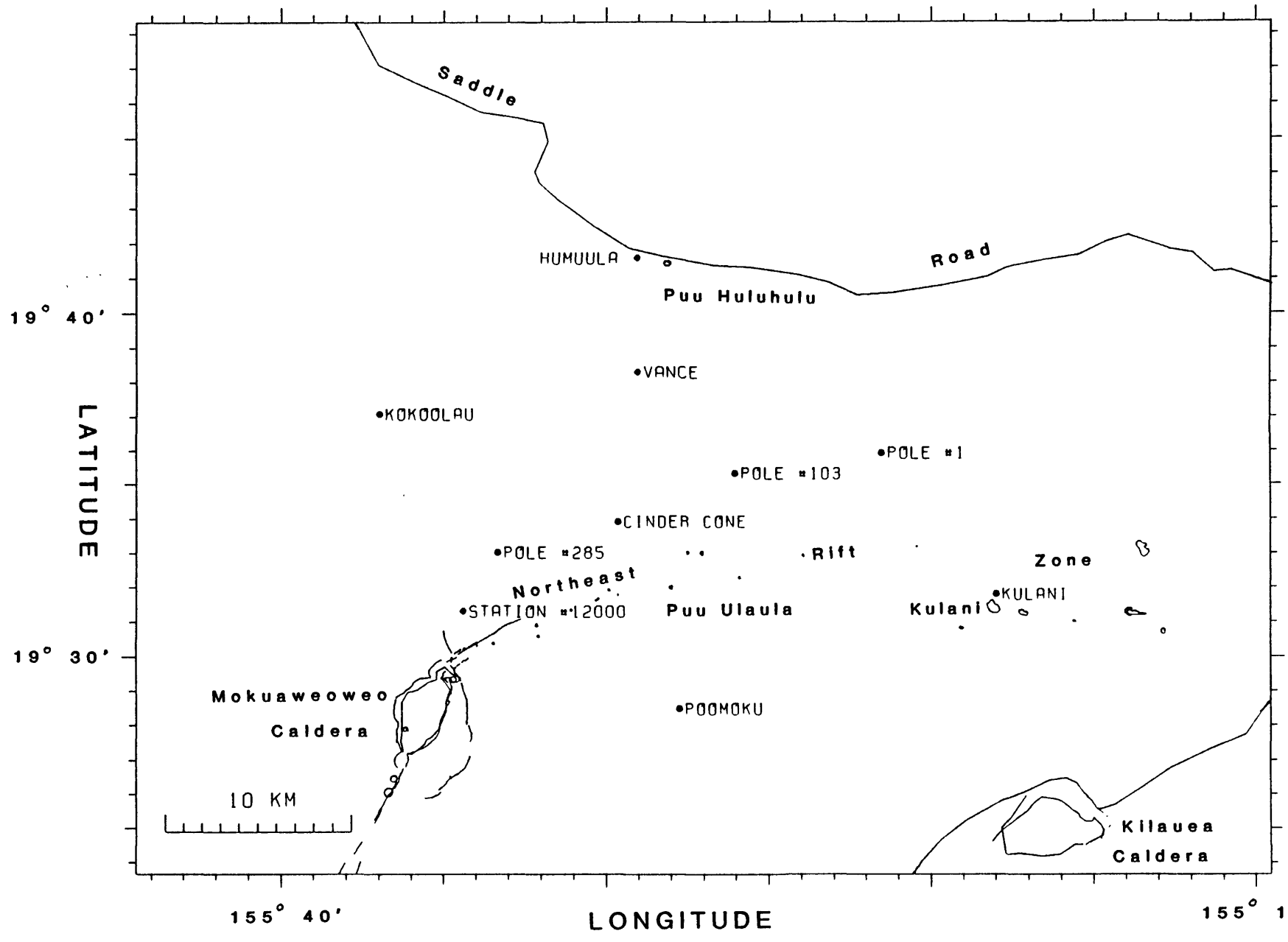
PREVIOUS NAME : None
MAP COORDINATES : N 19 28.15 W155 35.03 Mauna Loa
STATION DATA : Ly = 30.00 m, Lz = 30.00 m, Theta = 71.0, Phi = 131.0
STATION EQUATION : T(n) = 0.253 d(Y-X) — 0.125 d(X-Z)
T(e) = 0.290 d(Y-X) + 0.364 d(X-Z)

SUMMIT CABIN station is located on the eastern edge of Mokuaweoweo caldera, approximately 2.1 km east-northeast of the 1940 Cone on the summit of Mauna Loa in Hawaii Volcanoes National Park. The station is at 13,260' elevation, 50 m east of the Mauna Loa Summit Cabin The SUMMIT CABIN station is reached by helicopter and is set up to use 1.5 m invar leveling rods.



MAUNA LOA NORTHEAST RIFT ZONE AND NORTH FLANK DRYTILT STATIONS

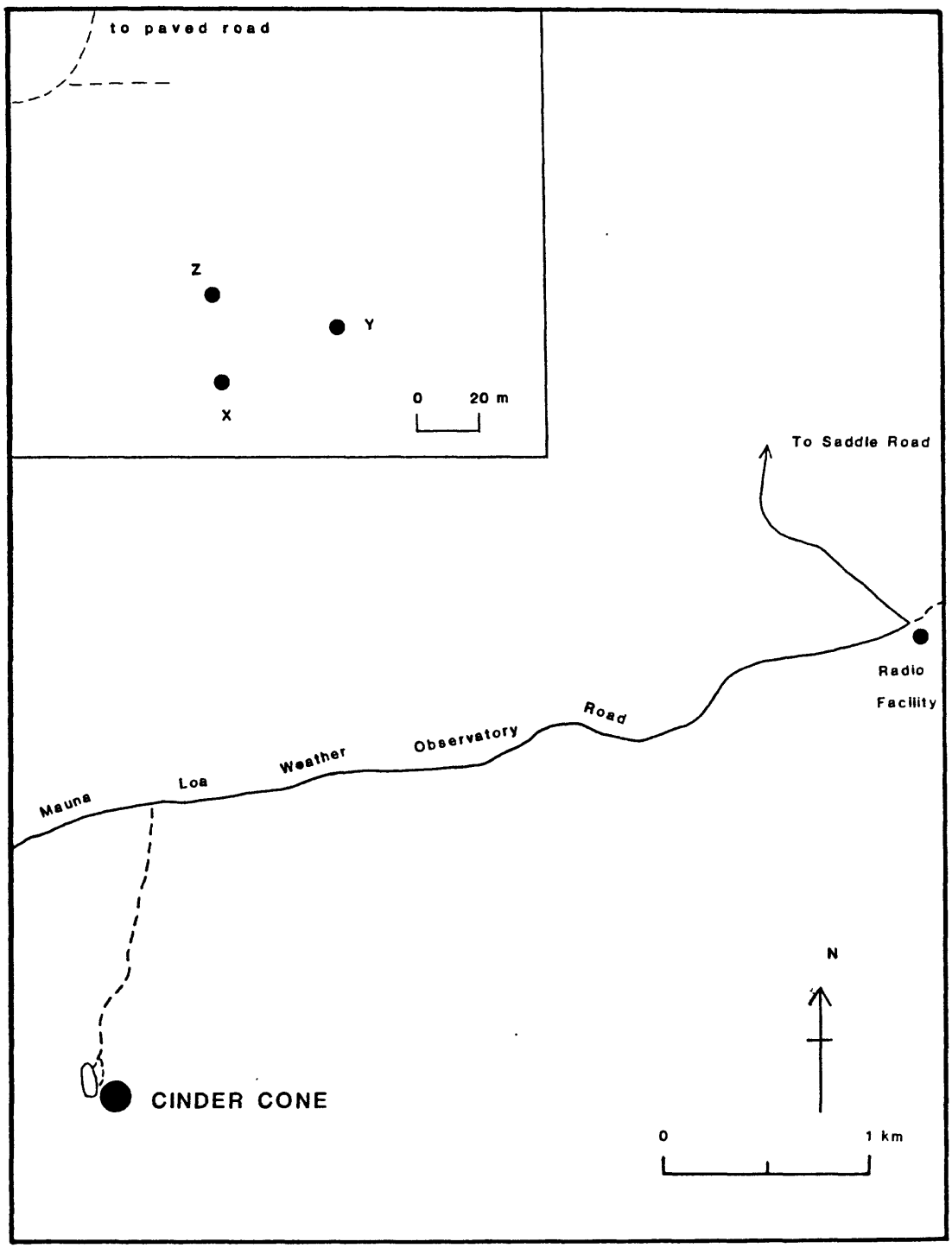
MAUNA LOA NORTHEAST RIFT ZONE AND NORTH FLANK DRYTILT STATIONS



CINDER CONE (6/5/75 to present)

PREVIOUS NAME :	None
MAP COORDINATES :	N 19 33.91' W155 29.66' Puu Ulaula
STATION DATA :	Ly = 41.00 m, Lz = 28.60 m, Theta = 26.0, Phi = 94.0
STATION EQUATION :	T(n) = 0.018 d(Y-X) − 0.339 d(X-Z)
	T(e) = 0.262 d(Y-X) + 0.165 d(X-Z)

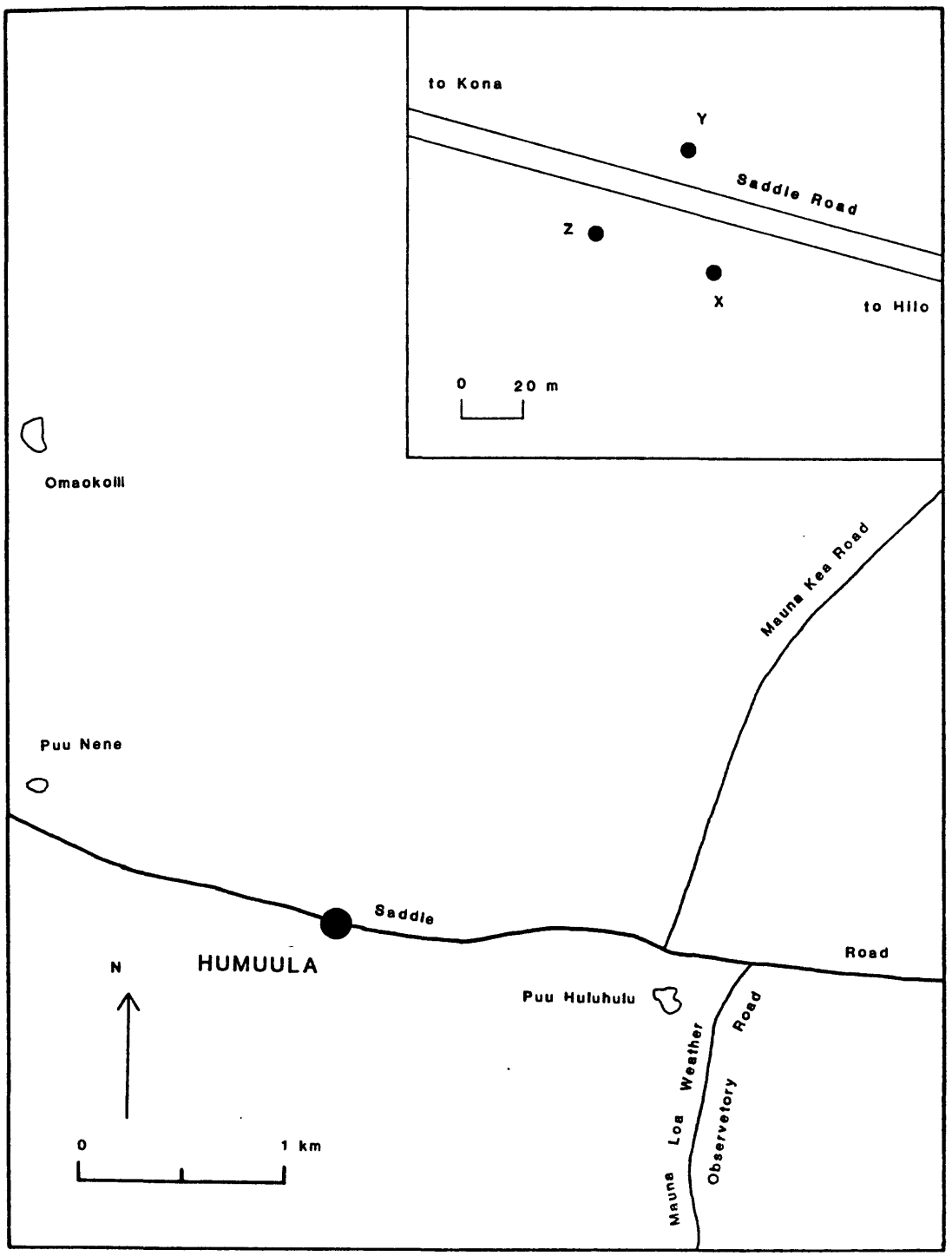
CINDER CONE station is located approximately 4.5 km northwest of Puu Ulaula near the northeast rift zone of Mauna Loa. From the Saddle road, go 8.8 miles on the Mauna Loa Weather Observatory road to reach a radio facility on the left. Keep to the right and continue following the paved road for 2.5 miles to reach a dirt road on the left. Turn left and go 0.9 mile to reach the CINDER CONE station.



HUMUULA (1/7/81 to present)

PREVIOUS NAME :	None
MAP COORDINATES :	N 19 41.59' W155 29.06' Puu Oo
STATION DATA :	Ly = 40.70 m, Lz = 39.90 m, Theta = 101.5, Phi = 161.5
STATION EQUATION :	T(n) = 0.274 d(Y-X) + 0.058 d(X-Z)
	T(e) = 0.092 d(Y-X) + 0.283 d(X-Z)

HUMUULA station is located approximately 1.65 km west of Puu Huluhulu on the north flank of Mauna Loa. From the intersection with the road to the Mauna Loa Weather Observatory, go 1.3 miles west, toward Kona, on the Saddle road to reach the HUMUULA station. The station is located 130 meters east of milepost 29.

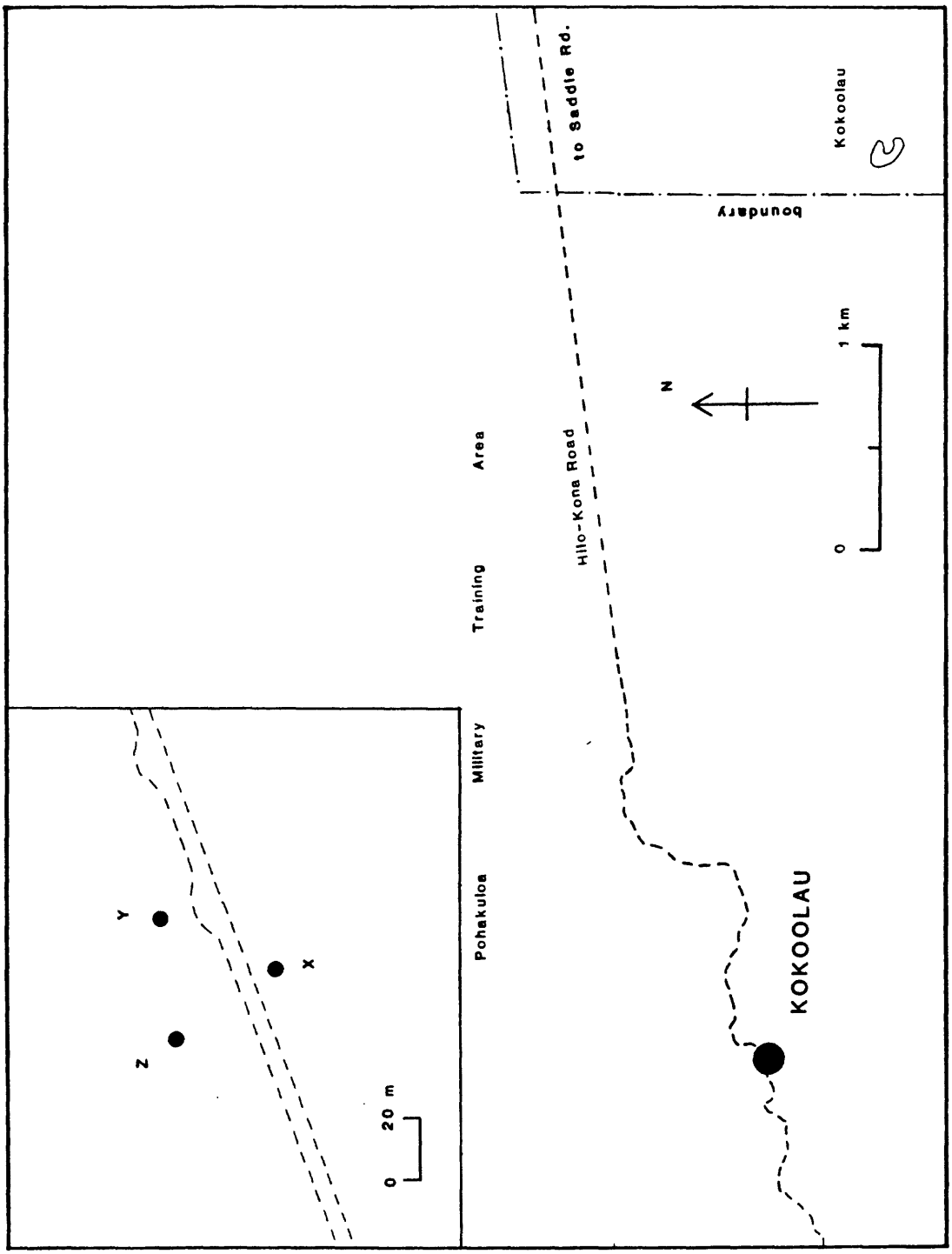


KOKOOLAU (6/17/76 to present)

PREVIOUS NAME :	None
MAP COORDINATES :	N 19 37.08' W155 36.98' Kokoolau
STATION DATA :	Ly = 39.90 m, Lz = 40.14 m, Theta = 66.0, Phi = 126.0
STATION EQUATION :	T(n) = 0.170 d(Y-X) — 0.117 d(X-Z)
	T(e) = 0.234 d(Y-X) + 0.263 d(X-Z)

KOKOOLAU station is located approximately 17.7 km southwest of Puu Huluhulu on the north flank of Mauna Loa in the Pohakuloa Military Training Area. From the Saddle Road, go 4.3 miles on the Mauna Loa Weather Observatory Road to reach a 4-wheel drive dirt road on the right (the Hilo-Kona Road). Turn right and go 9.0 miles to reach the KOKOOLAU station. Permission must be obtained from the military before entering this area.

note: see page 51 for access information (Pohakuloa Military).

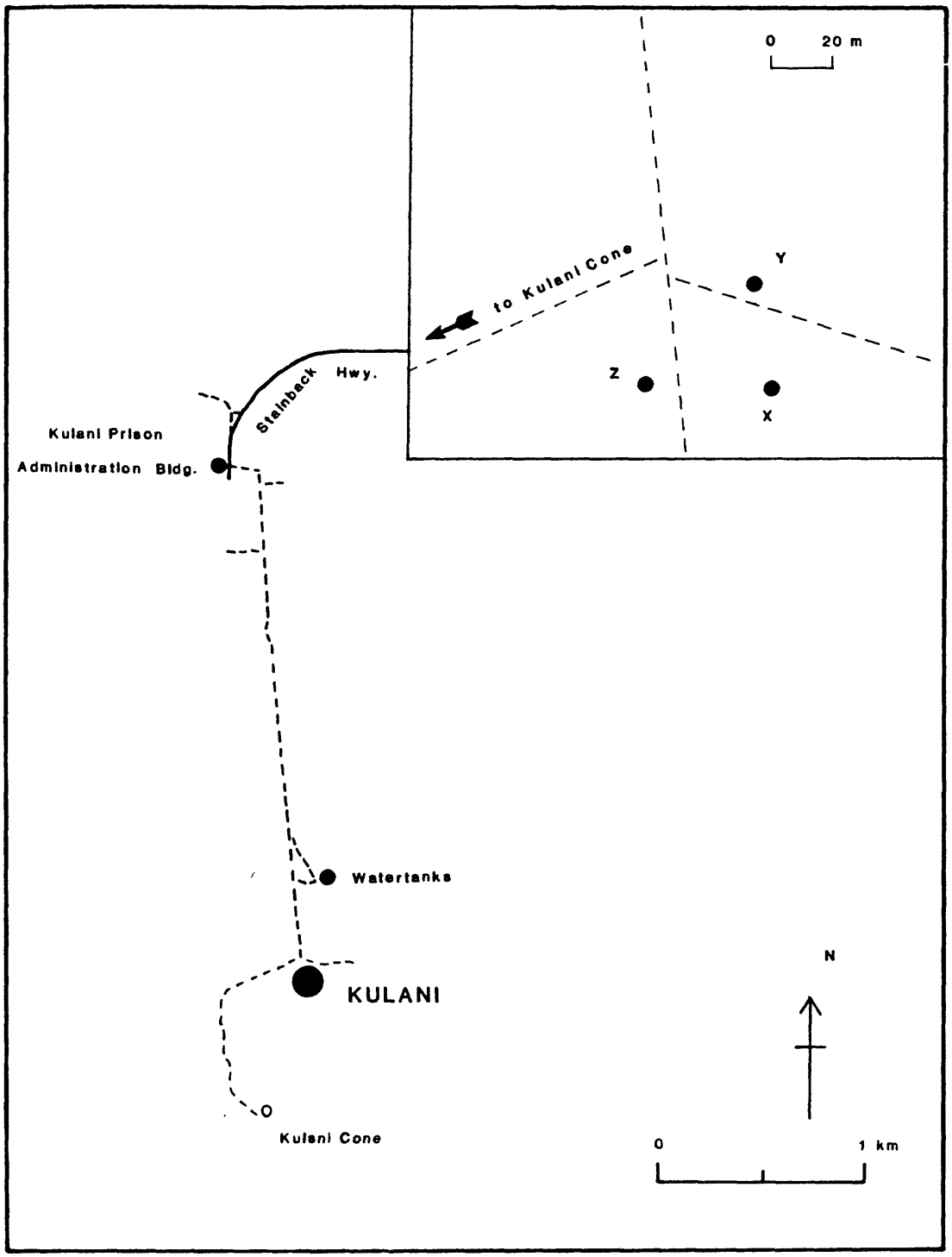


KULANI (3/24/76 to present)

PREVIOUS NAME : None
MAP COORDINATES : N 19 31.80' W155 18.01' Kulani
STATION DATA : Ly = 35.02 m, Lz = 39.56 m, Theta = 109.5, Phi = 176.5
STATION EQUATION : T(n) = 0.310 d(Y-X) + 0.092 d(X-Z)
T(e) = 0.019 d(Y-X) + 0.259 d(X-Z)

KULANI station is located approximately 800 m north-northeast of Kulani Cone on the northeast rift zone of Mauna Loa on the grounds of the Kulani Prison. Go to the end of Stainback Highway to reach the Kulani Prison Camp. From the administration office, go 0.1 mile east to reach the road to Kulani Cone on the right side. Turn right and go 1.6 miles to reach a fork in the road. Turn left and go 30 meters to reach the KULANI station.

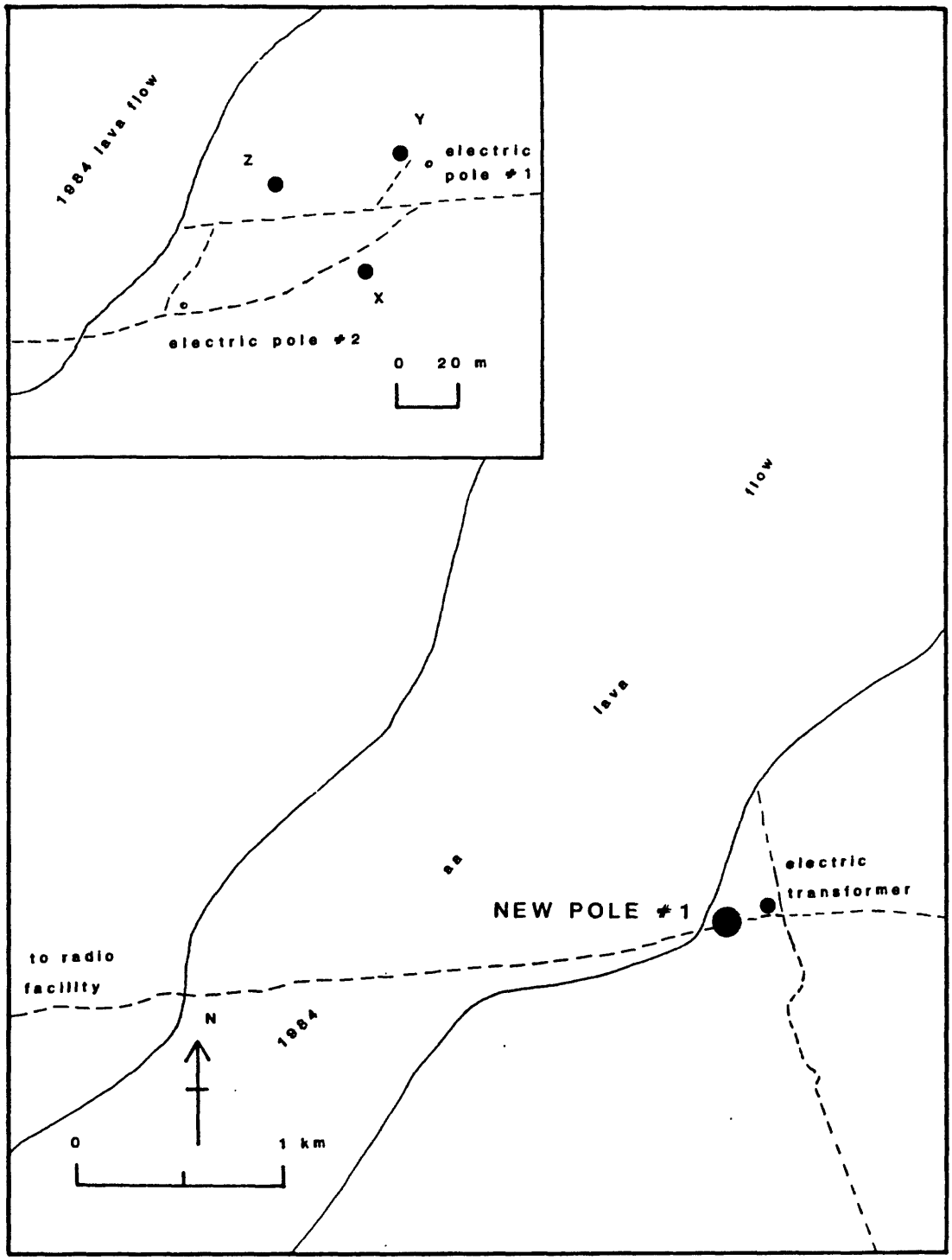
note: see page 51 for access information (Kulani Prison).



NEW POLE #1 (1/15/85 to present)

PREVIOUS NAME :	POLE #1 (7/10/75 to 12/14/83)
MAP COORDINATES :	N 19 35.93' W155 21.53' Kulani
STATION DATA :	Ly = 40.00 m, Lz = 40.00 m, Theta = 74.0, Phi = 134.0
STATION EQUATION :	T(n) = 0.201 d(Y-X) − 0.080 d(X-Z)
	T(e) = 0.208 d(Y-X) + 0.277 d(X-Z)

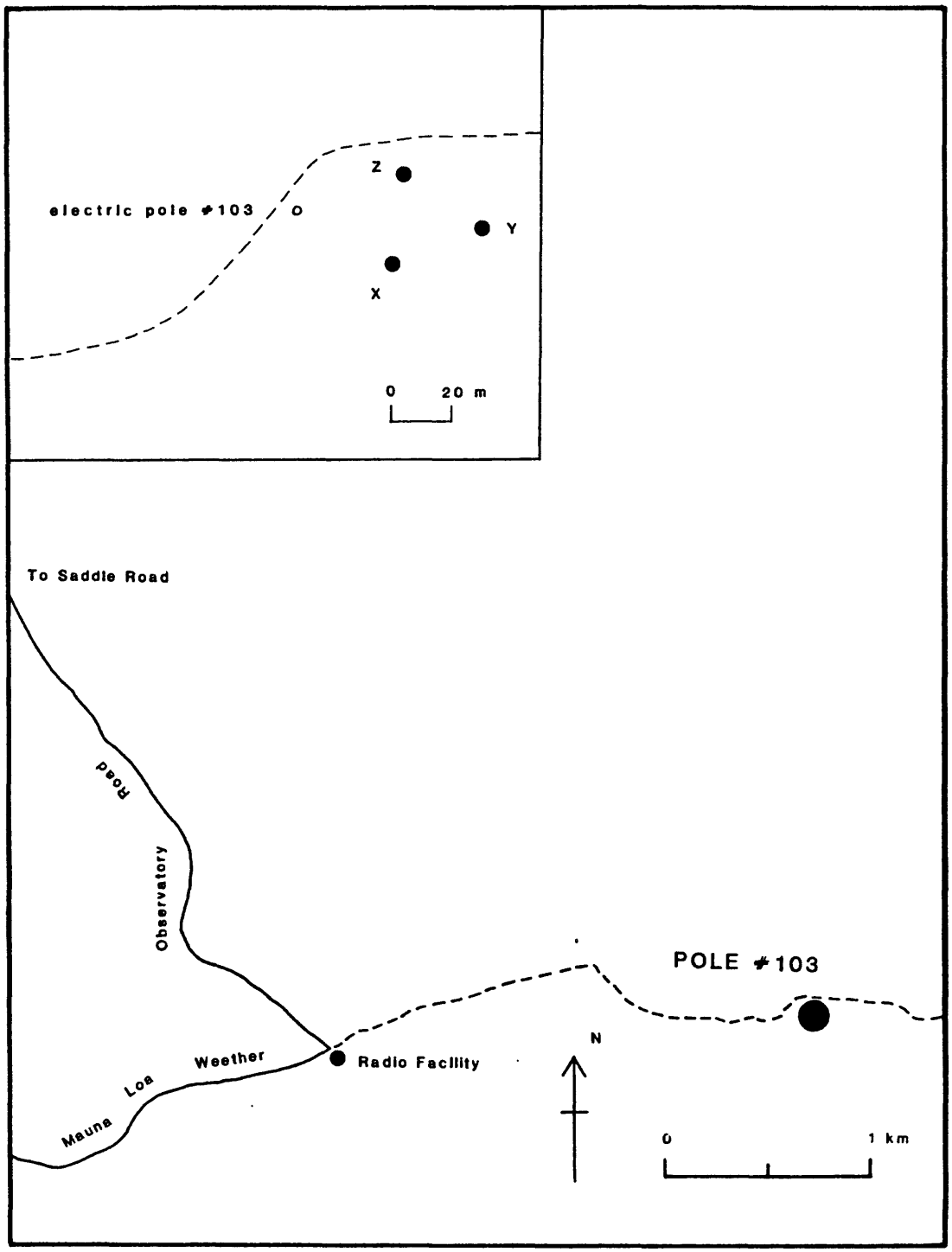
NEW POLE #1 station is located approximately 10.3 km northwest of Kulani cone near the northeast rift zone of Mauna Loa. From the Saddle road, go 8.8 miles on the Mauna Loa Weather Observatory road to reach a radio facility on left. Turn left on to a 4-wheel drive dirt road and go 7.3 miles to reach the NEW POLE #1 station. The station is 100 m east of the 1984 lava flow and is between electric poles #1 and #2.



POLE #103 (6/5/75 to present)

PREVIOUS NAME :	None
MAP COORDINATES :	N 19 35.33' W155 26.05' Puu Ulaula
STATION DATA :	Ly = 30.00 m, Lz = 30.00 m, Theta = 24.0, Phi = 84.0
STATION EQUATION :	T(n) = -0.040 d(Y-X) - 0.352 d(X-Z)
	T(e) = 0.383 d(Y-X) + 0.157 d(X-Z)

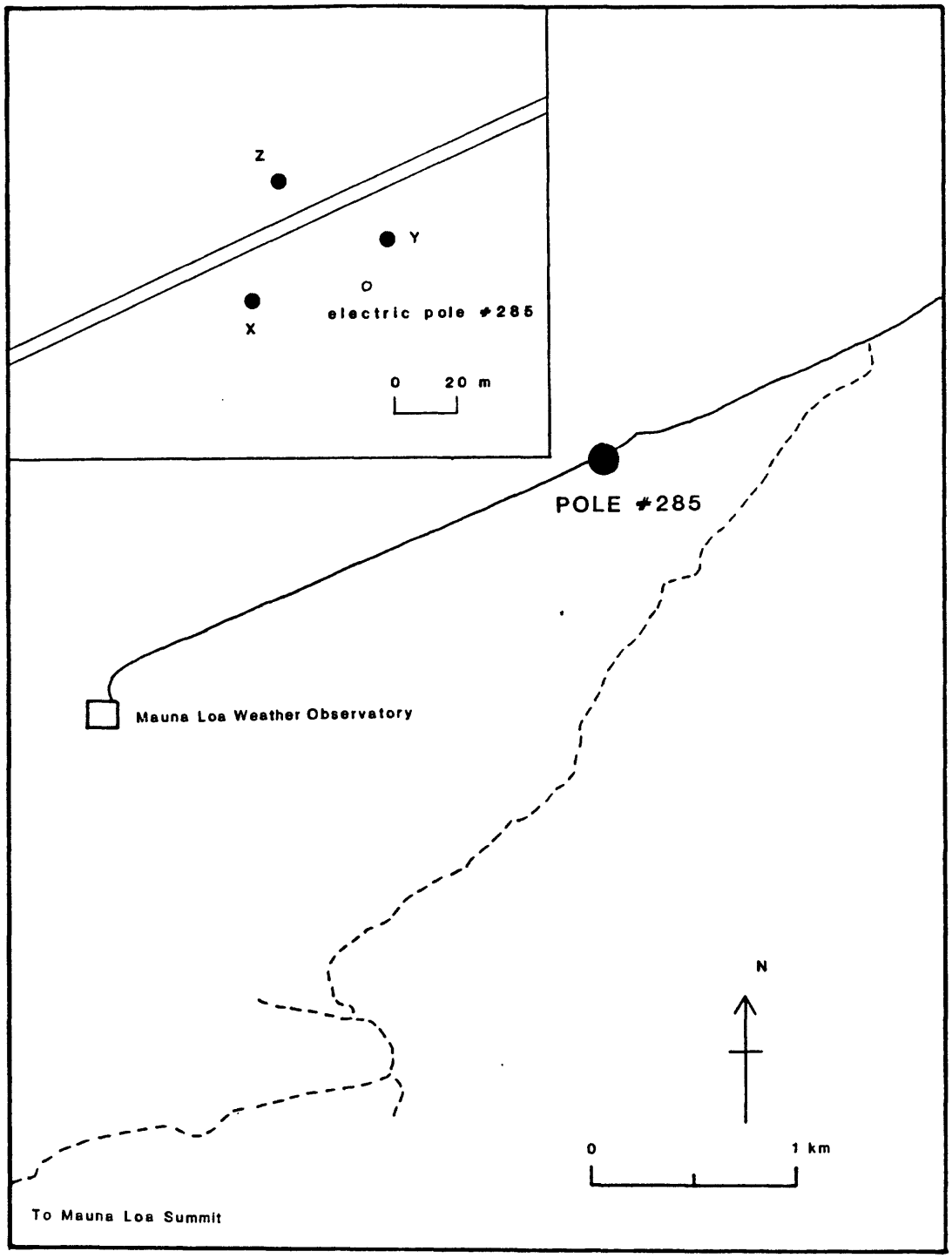
POLE #103 station is located approximately 7.0 km north-northwest of Puu Ulaula near the northeast rift zone of Mauna Loa. From the Saddle road, go 8.8 miles on the Mauna Loa Weather Observatory road to reach a radio facility on the left. Turn left on to a 4-wheel drive dirt road and go 1.7 miles to reach the POLE #103 station. The station is near electric pole #103.



POLE #285 (6/26/75 to present)

PREVIOUS NAME :	None
MAP COORDINATES :	N 19 33.02' W155 33.33' Kokoolau
STATION DATA :	Ly = 47.55 m, Lz = 38.86 m, Theta = 24.0, Phi = 78.0
STATION EQUATION :	T(n) = -0.054 d(Y-X) - 0.291 d(X-Z)
	T(e) = 0.254 d(Y-X) + 0.129 d(X-Z)

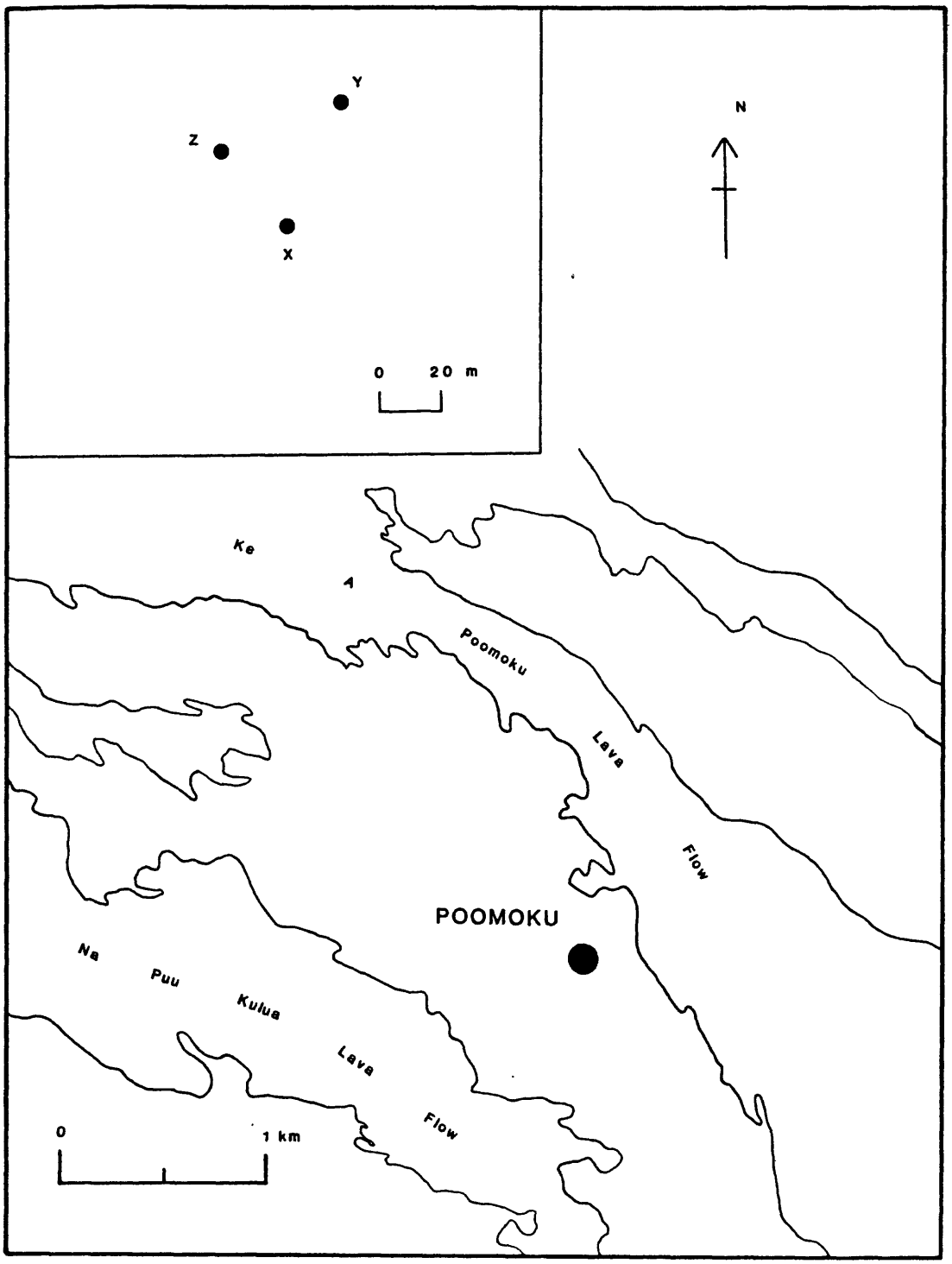
POLE #285 station is located approximately 9.6 km west northwest of Puu Ulaula near the northeast rift zone of Mauna Loa. From the Saddle road, go 8.8 miles on the Mauna Loa Weather Observatory road to reach a radio facility on the left. Keep to the right and continue following the paved road for 7.4 miles to reach the POLE #285 station. This station is near an electric pole #285.



POOMOKU (3/7/76 to present)

PREVIOUS NAME :	None
MAP COORDINATES :	N 19 28.48' W155 27.75' Kipuka Pakekake Quad.
STATION DATA :	Ly = 42.86 m, Lz = 32.43 m, Theta = 67.0, Phi = 131.0
STATION EQUATION :	T(n) = 0.169 d(Y-X) − 0.133 d(X-Z)
	T(e) = 0.194 d(Y-X) + 0.316 d(X-Z)

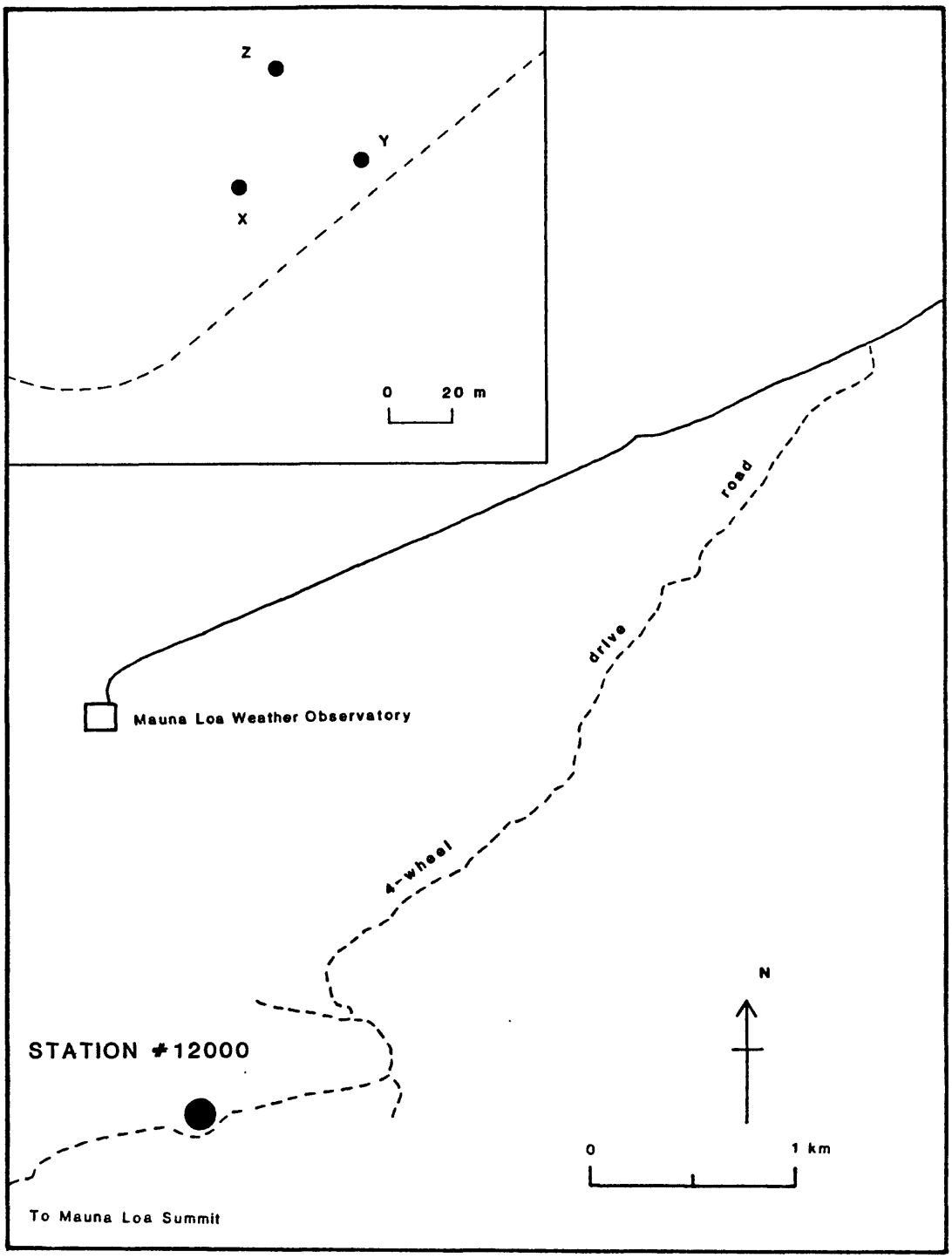
POOMOKU station is located approximately 6.5 km south of Puu Ulaula on the east flank of Mauna Loa in Hawaii Volcanoes National Park. The station is at the 8,440' elevation on black pahoehoe lava between the Kulua and Poomoku flows. POOMOKU station is reached by helicopter and and is set up to use 1.5 m invar leveling rods.



STATION #12000 (6/5/75 to present)

PREVIOUS NAME - None
MAP COORDINATES : N 19 31.30' W155 34.40' Kokoolau
STATION DATA : Ly = 40.00 m, Lz = 40.00 m, Theta = 11.5, Phi = 71.5
STATION EQUATION : $T(n) = -0.092\ d(Y-X) - 0.283\ d(X-Z)$
$T(e) = 0.274\ d(Y-X) + 0.058\ d(X-Z)$

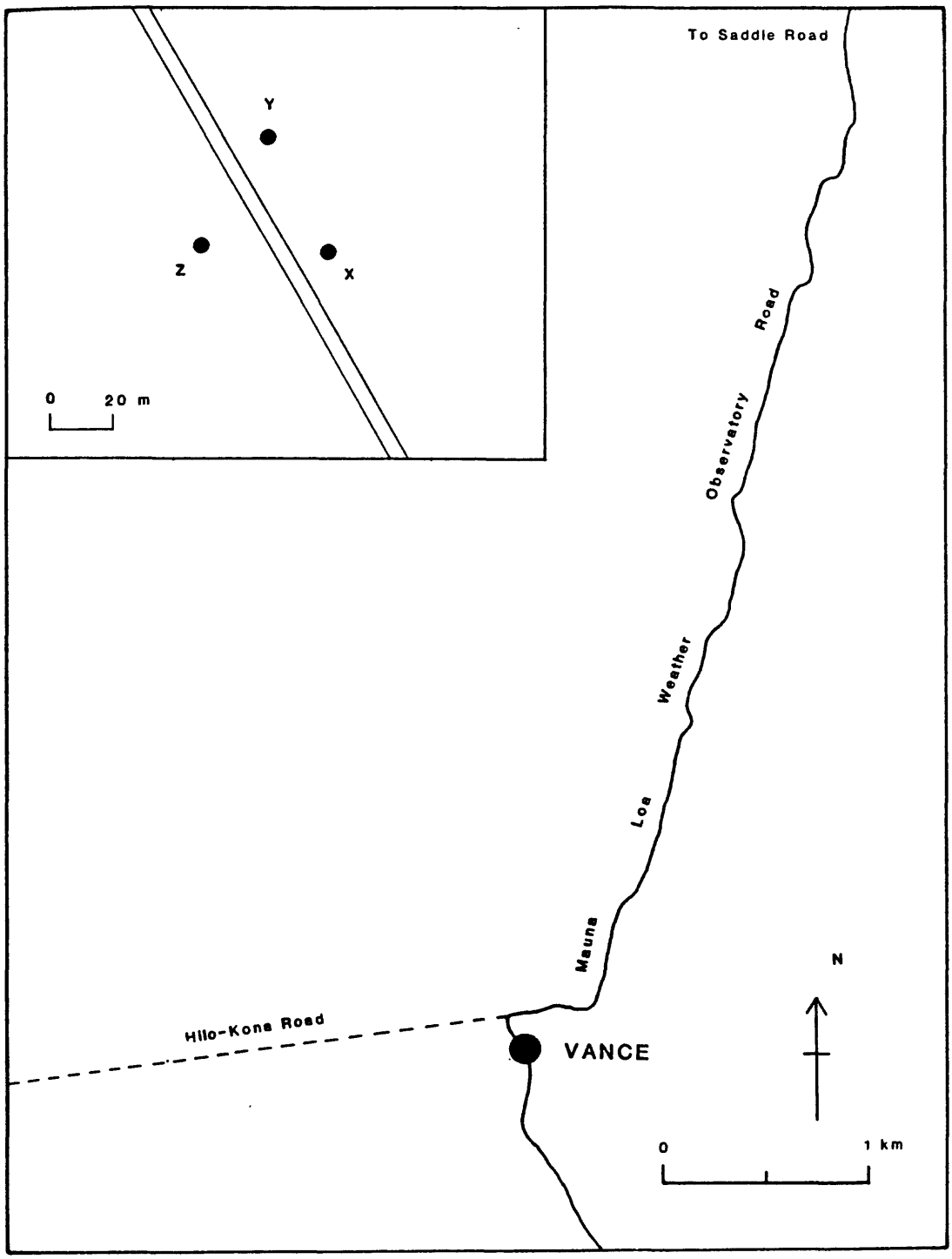
STATION #12000 is located approximately 11.5 km west of Puu Ulaula on the northeast rift zone of Mauna Loa. From the Saddle road, go 8.8 miles on the Mauna Loa Weather Observatory road to reach a radio facility on the left. Keep to the right and continue following the paved road for 6.5 miles to reach the 4-wheel drive dirt road to the summit on the left side. Turn left and go 2.9 miles to reach a fork in the road. Turn left and go 0.2 mile to reach another fork. Turn right and go 0.5 mile to reach the STATION #12000 station.



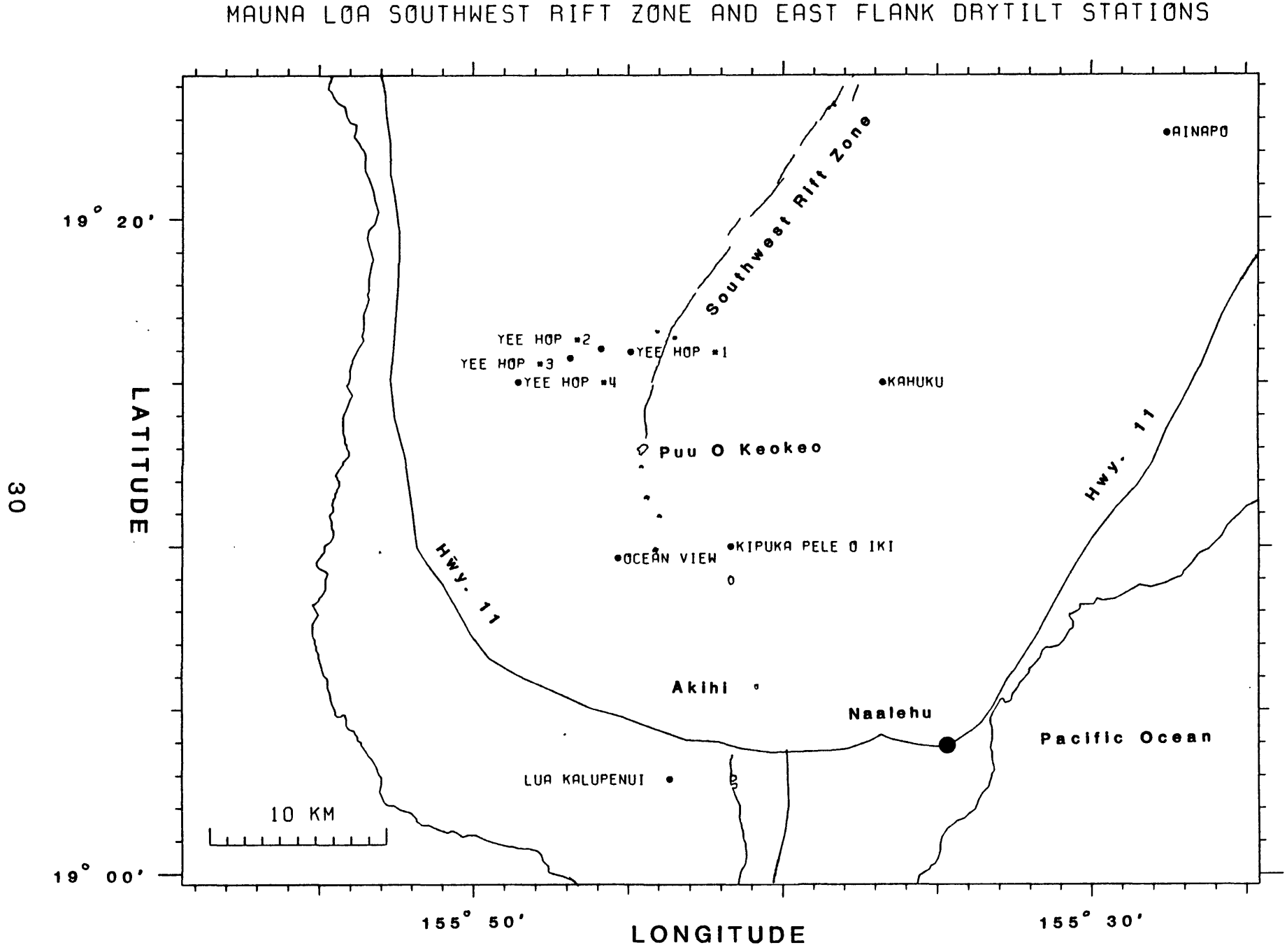
VANCE (1/4/77 to present)

PREVIOUS NAME :	None
MAP COORDINATES :	N 19 38.30' W155 29.03' Puu Oo
STATION DATA :	Ly = 40.70 m, Lz = 39.90 m, Theta = 116.0, Phi = 176.0
STATION EQUATION :	T(n) = 0.283 d(Y-X) + 0.127 d(X-Z)
	T(e) = 0.020 d(Y-X) + 0.260 d(X-Z)

VANCE station is located approximately 5.8 km south-southwest of Puu Hulululu near the northeast rift zone of Mauna Loa. From the Saddle road, go 4.3 miles on the Mauna Loa Weather Observatory road to reach a 4-wheel drive dirt road (the Hilo-Kona road) on the right. Continue on the paved road for 0.1 mile to reach the VANCE station.



MAUNA LOA SOUTHWEST RIFT ZONE AND EAST FLANK DRYTILT STATIONS

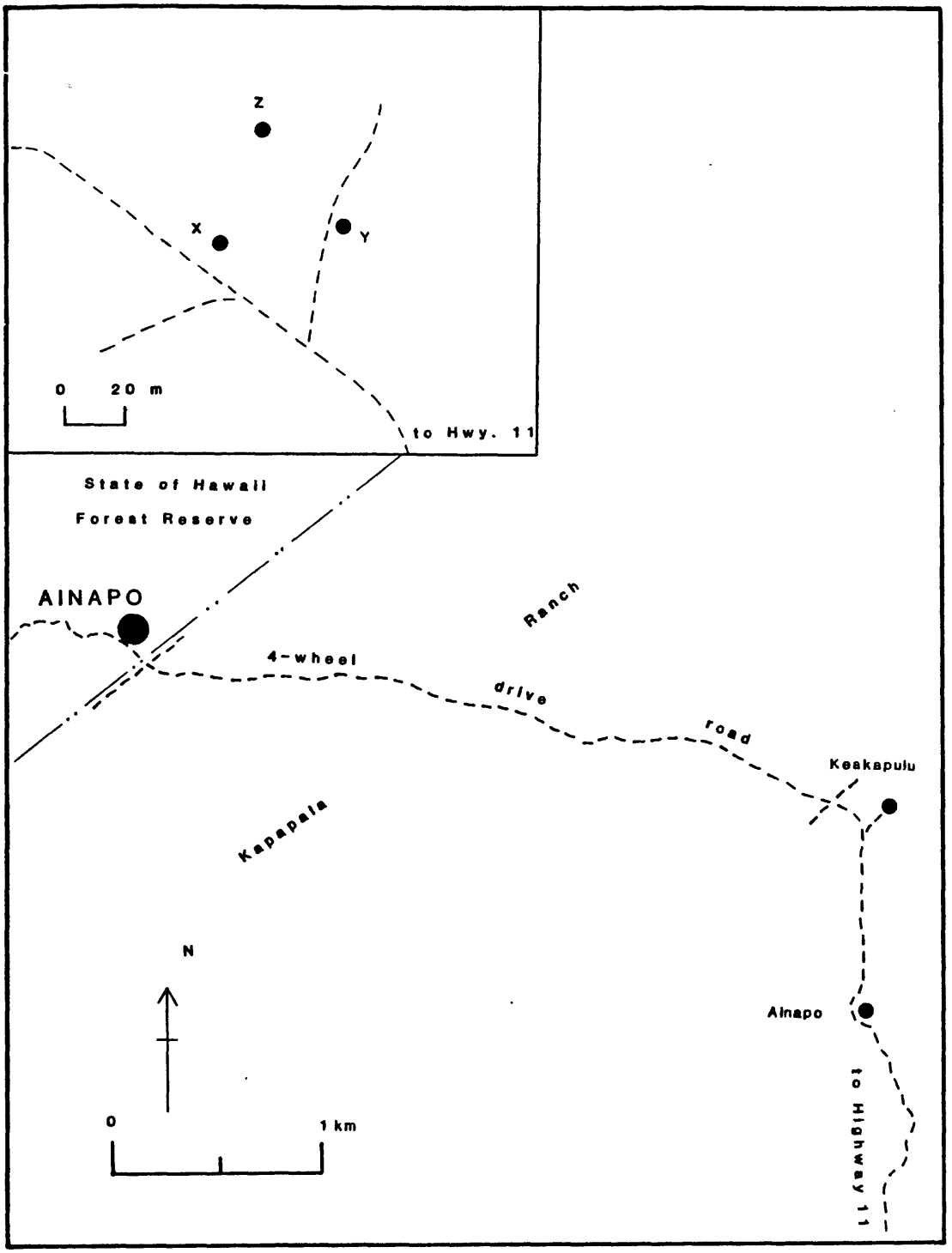

MAUNA LOA SOUTHWEST RIFT ZONE AND EAST FLANK DRYTILT STATIONS
Southwest Rift Zone
AINAPO
YEE HOP #2
YEE HOP #1
YEE HOP #3
YEE HOP #4
KAHUKU
Puu O Keokeo
Hwy. 11
Hwy. 11
OCEAN VIEW
KIPUKA PELE O IKI
Akihi
Naalehu
Pacific Ocean
LUA KALUPENUI
10 KM
19° 20'
19° 00'
155° 50'
155° 30'
LATITUDE
LONGITUDE

AINAPO (6/29/76 to present)

PREVIOUS NAME :	None
MAP COORDINATES :	N 19 22.57′ W155 27.55′
STATION DATA :	Ly = 40.72 m, Lz = 40.72 m, Theta = 10.0, Phi = 70.0
STATION EQUATION :	T(n) = −0.097 d(Y-X) − 0.279 d(X-Z)
	T(e) = 0.267 d(Y-X) + 0.049 d(X-Z)

AINAPO is located approximately 18 km southeast of Mokuaweoweo Caldera on State of Hawaii Forest Reserve land. From HVO, drive 0.8 mile clockwise on Crater Rim Drive to reach the intersection with Mauna Loa Strip Road. Turn left and go 0.1 mile to reach the intersection with Highway 11. Turn left and go 10.1 miles to reach a locked gate to the Kapapala Ranch on the right. Go through the gate for 50 meters and turn left on to a paved one-lane road. Go 0.7 mile to reach a gate on the right. Turn right onto a 4 wheel drive road and go 6.2 miles to reach the boundary to the State of Hawaii Forest Reserve. Continue for 0.25 mile to reach the AINAPO station.

note: see page 51 for access information (Kapapala Ranch).

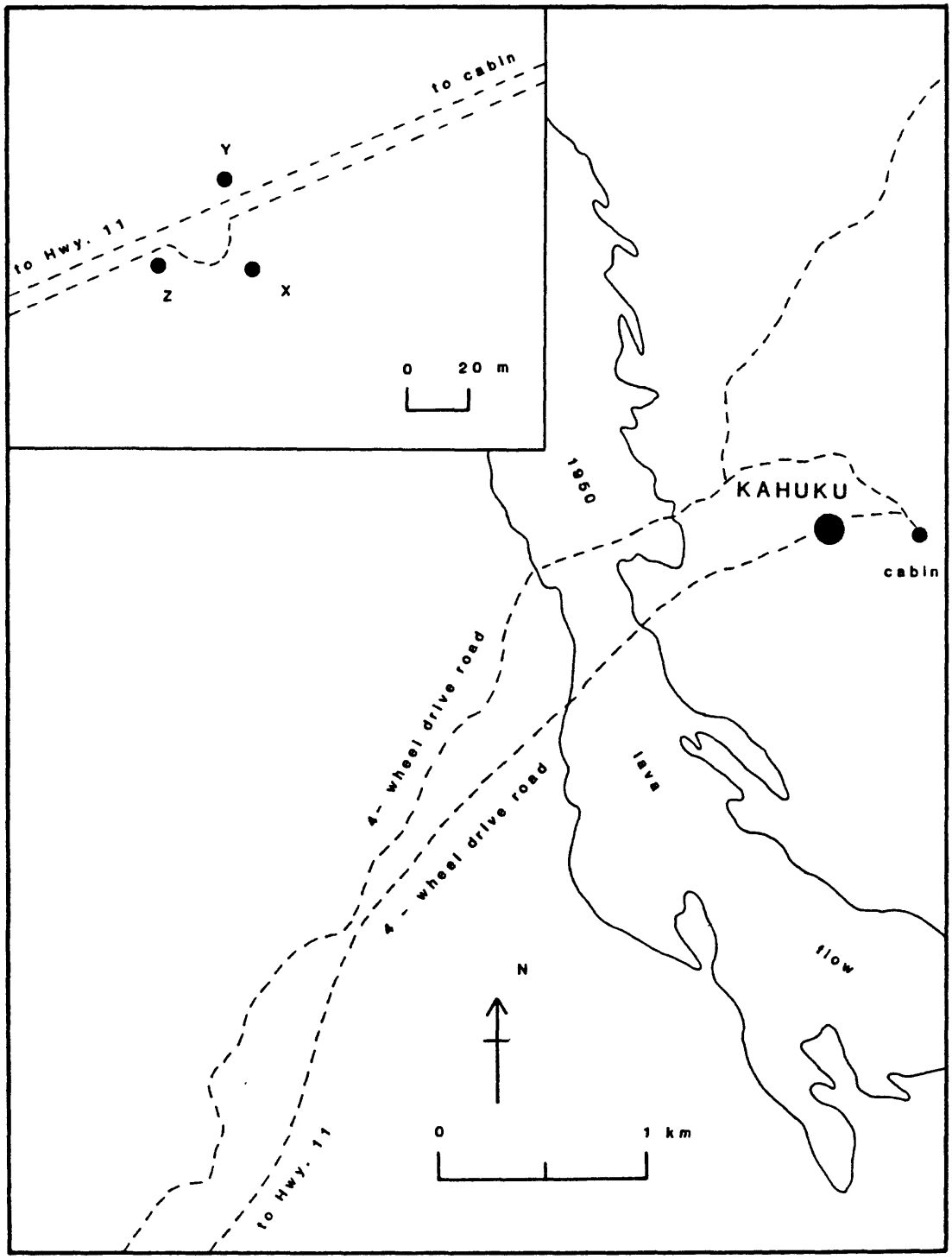


KAHUKU (4/21/77 to present)

PREVIOUS NAME : None
MAP COORDINATES : N 19 15.02' W155 36.78' Keaiwa Reservoir
STATION DATA : Ly = 30.11 m, Lz = 30.08 m, Theta = 118.0, Phi = 179.0
STATION EQUATION : T(n) = 0.379 d(Y-X) + 0.178 d(X-Z)
T(e) = 0.007 d(Y-X) + 0.335 d(X-Z)

KAHUKU station is located on private ranch land 14.3 km east northeast of Puu O Keokeo cone near the southwest rift zone of Mauna Loa. From the intersection of Highway 11 and South Point Road, drive 0.9 mile to reach an access road to Kahuku Ranch on the right side (just past the Kahuku Ranch sign). Turn right and go 0.5 mile to reach an intersection with a 4-wheel drive dirt road on the left. Turn left and go 15.4 miles through 2 locked gates to reach the east edge of the 1950 lava flow. Continue on the same road for 0.6 mile to reach the KAHUKU station (0.3 mile past the seismic station).

note: see page 51 for access information (Kahuku Ranch).

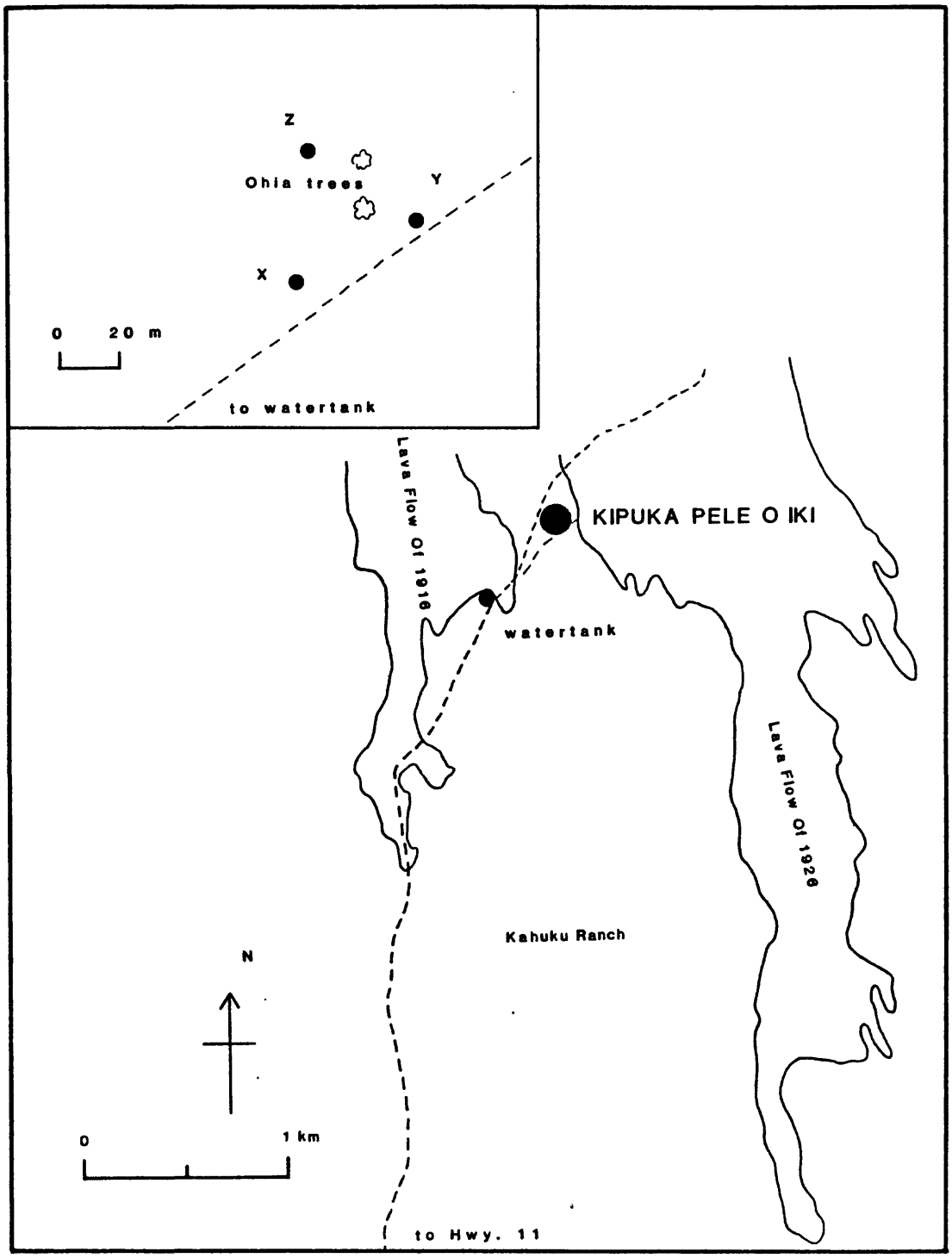


KIPUKA PELE O IKI (3/11/75 to present)

PREVIOUS NAME : None
MAP COORDINATES : N 19 9.91' W155 41.69' Puu O Keokeo
STATION DATA : Ly = 41.64 m, Lz = 41.64 m, Theta = 25.0, Phi = 85.0
STATION EQUATION : T(n) = -0.024 d(Y-X) - 0.251 d(X-Z)
T(e) = 0.276 d(Y-X) + 0.117 d(X-Z)

KIPUKA PELE O IKI station is located on private ranch land approximately 7.6 km southeast of Puu O Keokeo cone on the southwest rift zone of Mauna Loa. From the intersection of Highway 11 and South Point Road, drive 0.9 mile west to reach an access road to Kahuku Ranch on the right side (just past the Kahuku Ranch sign). Turn right and go 0.5 mile to reach an intersection with a 4-wheel drive dirt road on the left. Turn left and go 7.1 miles (through a locked gate) to reach an unlocked gate. Continue on for 0.55 mile to reach an obscure dirt road on the right side (just after reaching water tanks on the left). Turn right and go 0.2 mile to reach the KIPUKA PELE O IKI station.

note: see page 51 for access information (Kahuku Ranch).

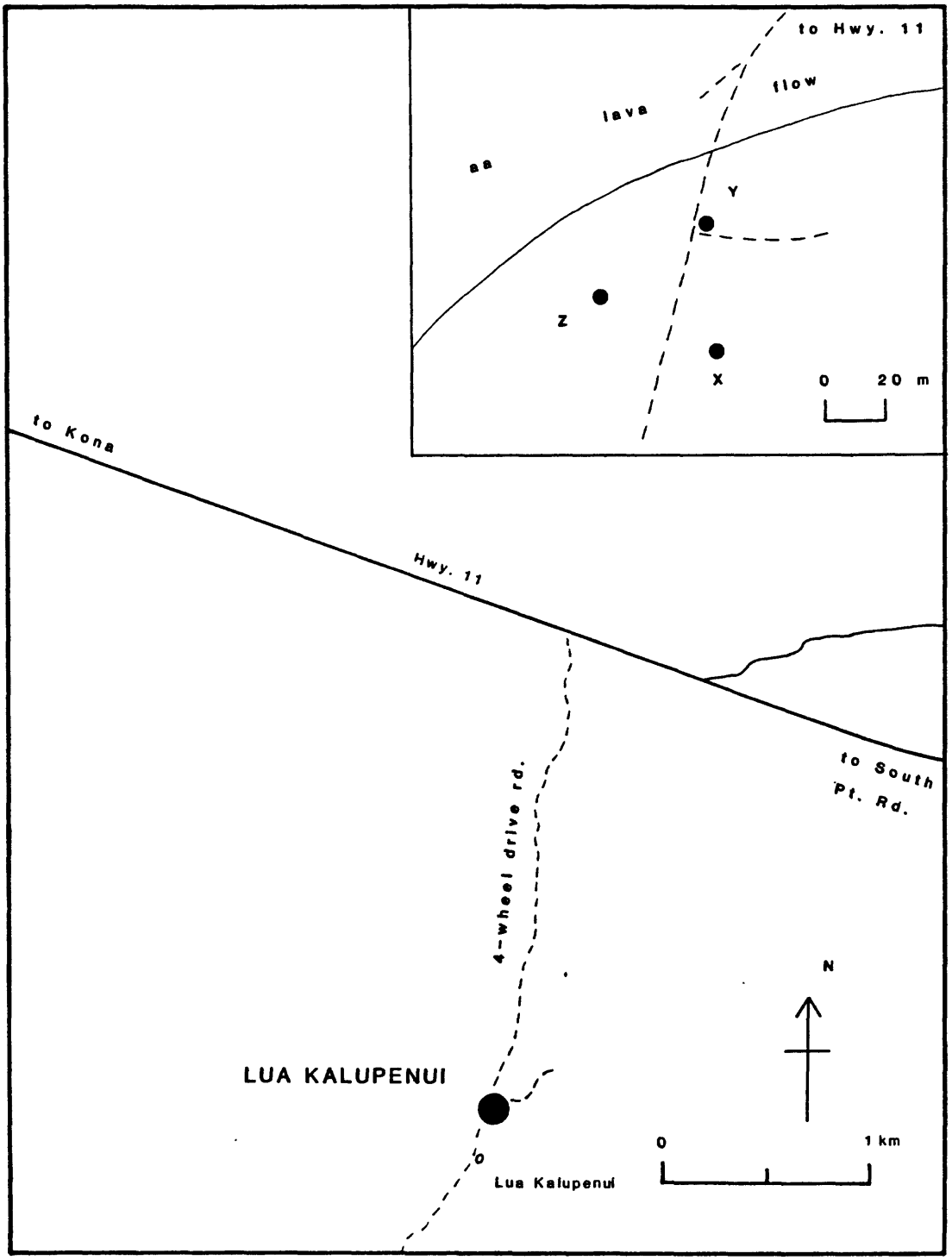


LUA KALUPENUI (3/11/75 to present)

PREVIOUS NAME : None
MAP COORDINATES : N 19 02.89' W155 43.65' Kahuku Ranch
STATION DATA : Ly = 40.00 m, Lz = 40.00 m, Theta = 96.0, Phi = 156.0
STATION EQUATION : T(n) = 0.264 d(Y-X) + 0.030 d(X-Z)
T(e) = 0.120 d(Y-X) + 0.287 d(X-Z)

LUA KALUPENUI station is located on private ranch land approximately 7.4 km southwest of Puu O Keokeo on the southwest rift zone of Mauna Loa. From the intersection of Highway 11 and South Point Road, drive 4.0 miles west to reach a 4-wheel drive dirt road with a locked gate on the left side (0.5 mile after milepost 73). Turn left and go 1.5 miles to reach the LUA KALUPENUI station.

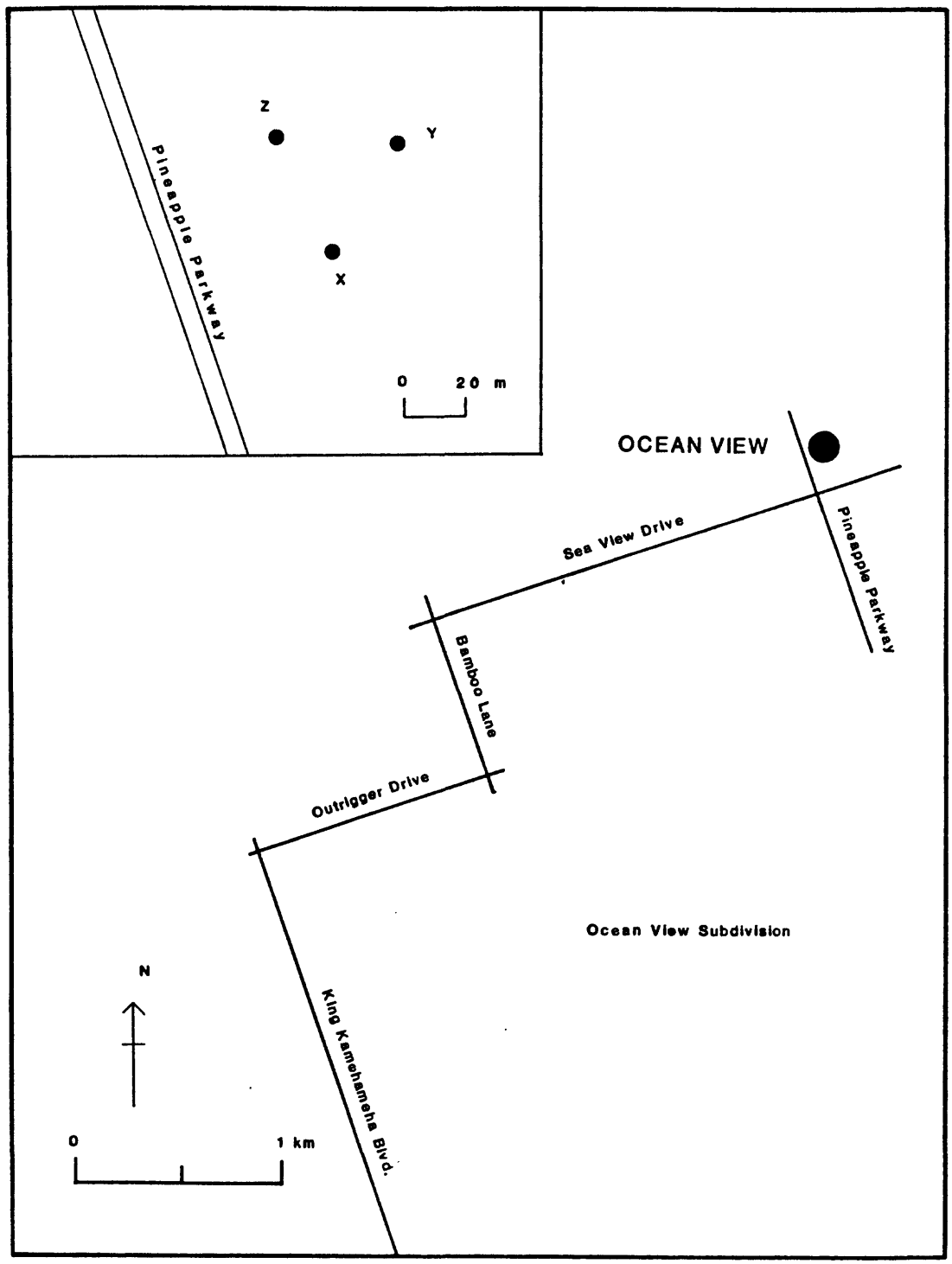
note: see page 51 for access information (Kahuku Ranch).



OCEAN VIEW (3/11/75 to present)

PREVIOUS NAME : None
MAP COORDINATES : N 19 09.65' W155 45.33' Papa
STATION DATA : Ly = 40.00 m, Lz = 40.00 m, Theta = 56.0, Phi = 116.0
STATION EQUATION : T(n) = 0.126 d(Y-X) — 0.161 d(X-Z)
T(e) = 0.259 d(Y-X) + 0.240 d(X-Z)

OCEAN VIEW station is located 6.2 km south of Puu O Keokeo in the Hawaiian Ocean View Estates subdivision on the southwest rift zone of Mauna Loa. From the intersection of Highway 11 and South Point Road, drive 6.3 miles to reach Kamehameha Blvd (0.15 mile past the milepost 76 sign) on the right side. Turn right and go 4.4 miles to reach Outrigger Drive. Turn right and go 0.75 mile to reach Bamboo Lane. Turn left and go 0.5 mile to reach Sea View Drive. Turn right and go 1.2 miles to to reach the Pineapple Parkway. Turn left and go 0.1 mile to reach the OCEAN VIEW station.

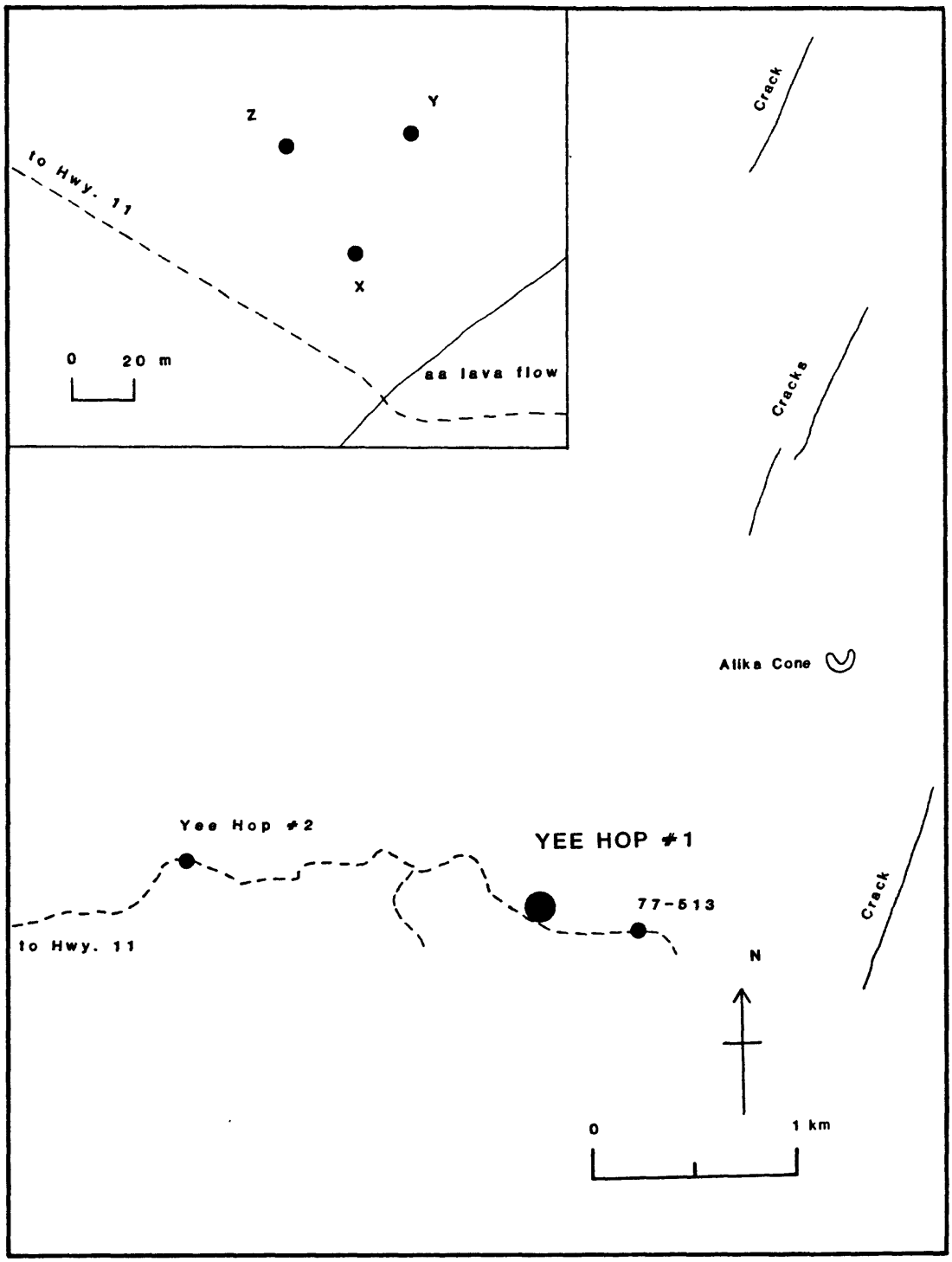


YEE HOP #1 (7/6/77 to present)

PREVIOUS NAME : None
MAP COORDINATES : N 19 15.95' W155 44.92' Alika Cone
STATION DATA : Ly = 40.00 m, Lz = 40.00 m, Theta = 65.0, Phi = 125.0
STATION EQUATION : T(n) = 0.166 d(Y-X) — 0.122 d(X-Z)
T(e) = 0.237 d(Y-X) + 0.262 d(X-Z)

YEE HOP #1 station is located on private ranch land 5.4 km north of Puu O Keokeo on the southwest rift zone of Mauna Loa. From the intersection of Highway 11 and South Point Road, drive 20.5 miles west to reach a locked gate to the Yee Hop Ranch on the right side (0.2 mile after mile marker 90). Turn right on to a 4-wheel drive dirt road and go 1.1 miles to reach a road on the left (just before the ruins of an ohia mill). Turn left and go 9.7 miles to reach the YEE HOP #1 station (0.3 mile before benchmark 77-513).

note: see page 51 for access information (Yee Hop Ranch).

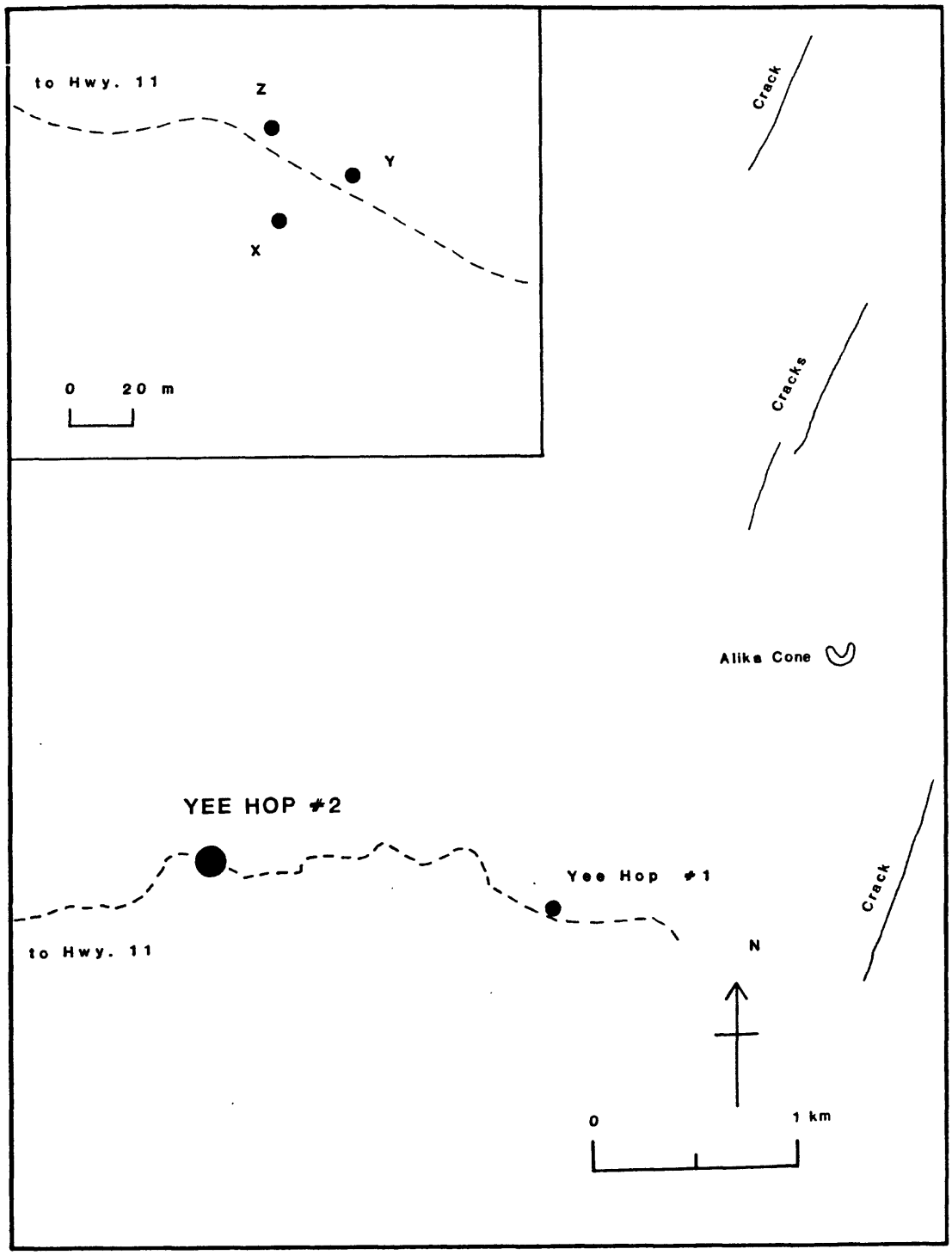


YEE HOP #2 (7/6/77 to present)

PREVIOUS NAME : None
MAP COORDINATES : N 19 16.01' W155 45.82' Puu Pohakuloa
STATION DATA : Ly = 28.65 m, Lz = 30.23 m, Theta = 30.0, Phi = 95.0
STATION EQUATION : T(n) = 0.034 d(Y-X) — 0.316 d(X-Z)
T(e) = 0.383 d(Y-X) + 0.183 d(X-Z)

YEE HOP #2 station is located on private ranch land 6.2 km north-northwest of Puu O Keokeo on the southwest rift zone of Mauna Loa. From the intersection of Highway 11 and South Point Road, drive 20.5 miles west to reach a locked gate to the Yee Hop Ranch on the right side (0.2 mile after mile marker 90). Turn right on to a 4-wheel drive dirt road and go 1.1 miles to reach a road on the left (just before the ruins of an ohia mill). Turn left and go 8.5 miles to reach the YEE HOP #2 station (1.2 miles before the YEE HOP #1 station).

note: see page 51 for access information (Yee Hop Ranch).

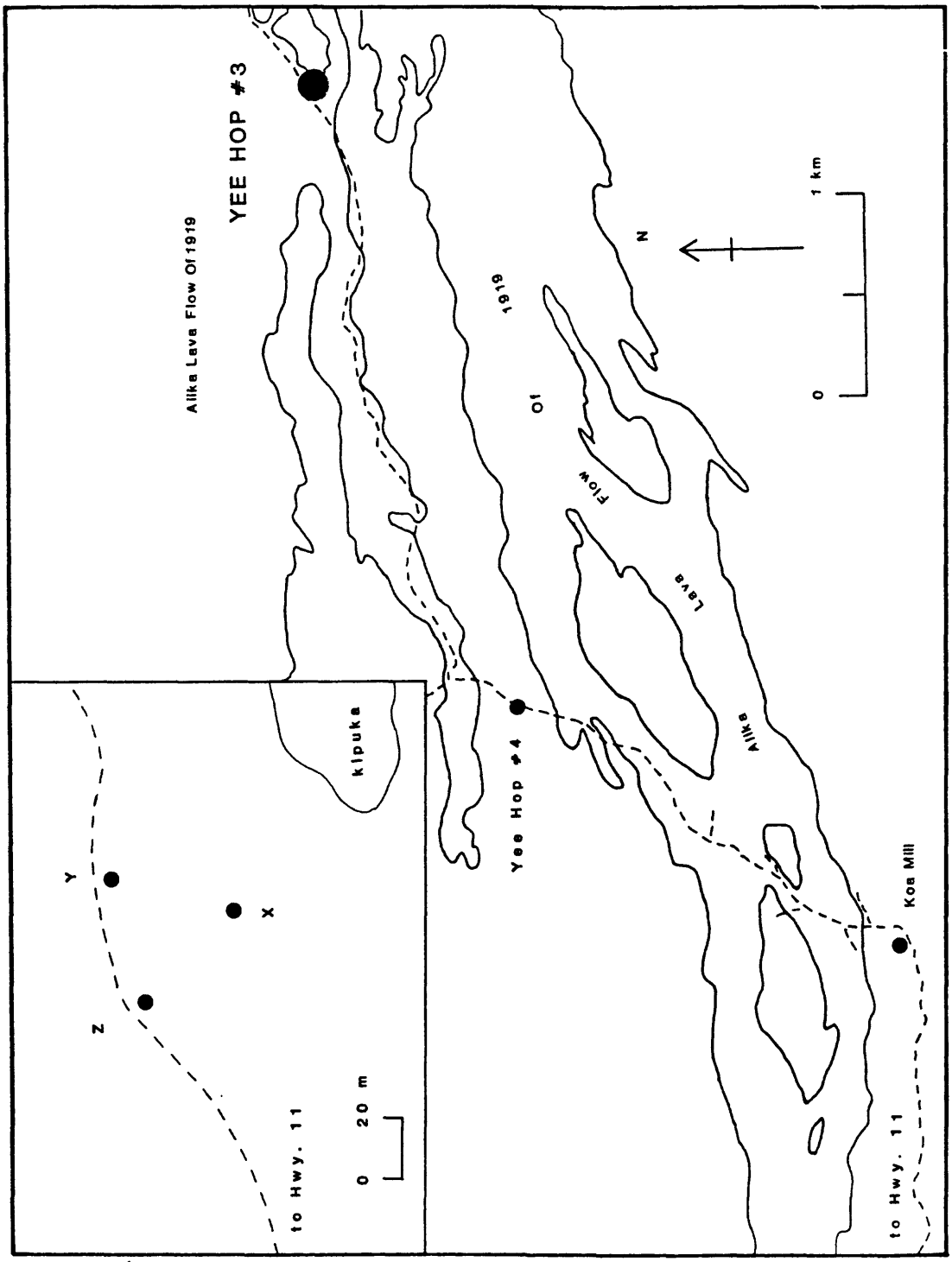


YEE HOP #3 (7/6/77 to present)

PREVIOUS NAME : None
MAP COORDINATES : N 19 15.70' W155 46.79' Puu Pohakuloa
STATION DATA : Ly = 40.02 m, Lz = 40.02 m, Theta = 75.0, Phi = 135.0
STATION EQUATION : T(n) = 0.204 d(Y-X) − 0.075 d(X-Z)
T(e) = 0.204 d(Y-X) + 0.279 d(X-Z)

YEE HOP #3 station is located on private ranch land 6.5 km northwest of Puu O Keokeo on the southwest rift zone of Mauna Loa. From the intersection of Highway 11 and South Point Road, drive 20.5 miles west to reach a locked gate to the Yee Hop Ranch on the right side (0.2 mile after mile marker 90). Turn right on to a 4-wheel drive dirt road and go 1.1 miles to reach a road on the left (just before the ruins of an ohia mill). Turn left and go 7.3 miles to reach the YEE HOP #3 station (50 m northwest of a small kipuka).

note: see page 51 for access information (Yee Hop Ranch).

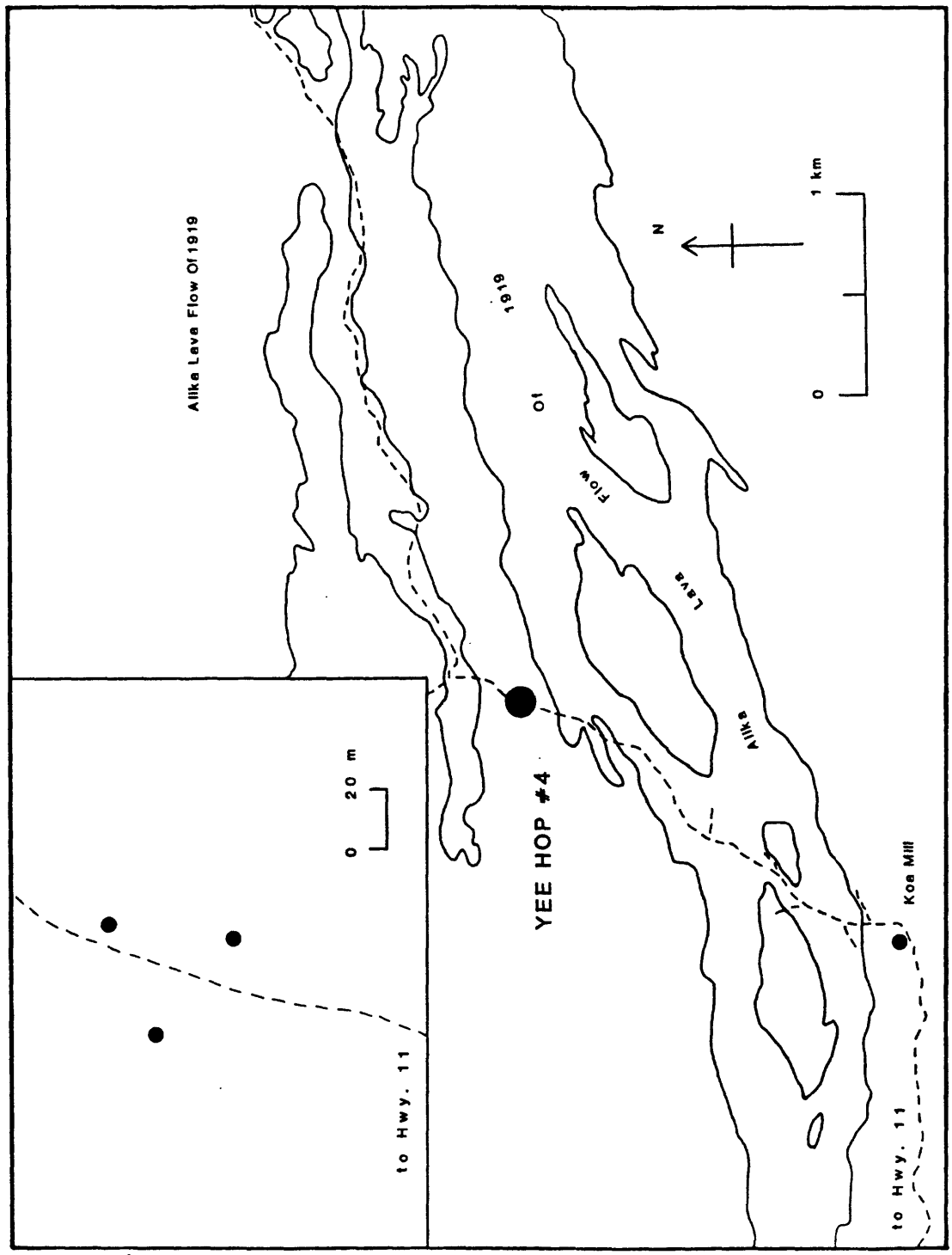


YEE HOP #4 (7/6/77 to present)

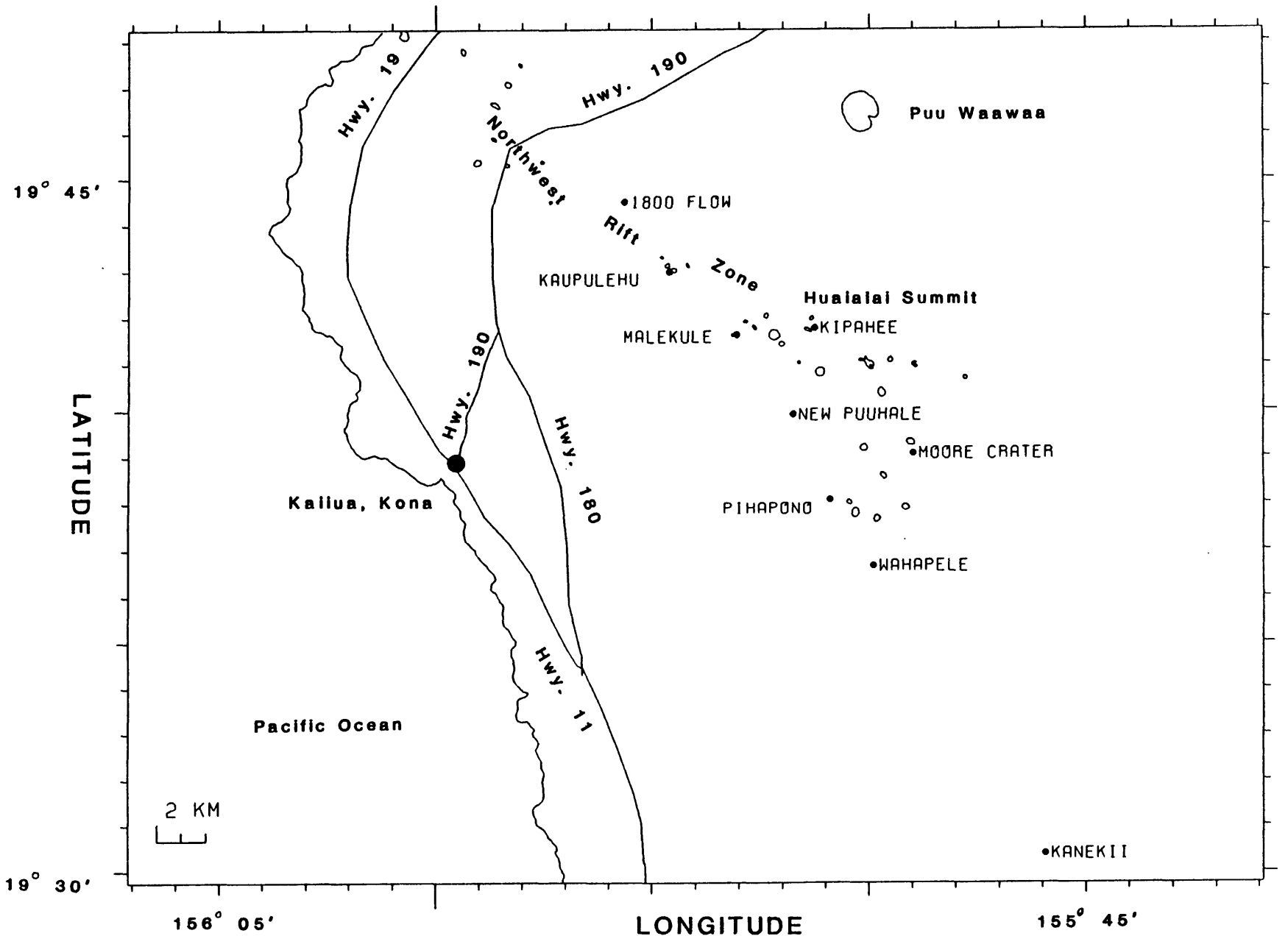
PREVIOUS NAME : None
MAP COORDINATES : N 19 15.12' W155 48.52' Puu Pohakuloa
STATION DATA : Ly = 40.02m, Lz = 40.80 m, Theta = 85.0, Phi = 142.4
STATION EQUATION : T(n) = 0.235 d(Y-X) — 0.025 d(X-Z)
T(e) = 0.184 d(Y-X) + 0.291 d(X-Z)

YEE HOP #4 station is located on private ranch land 8.0 km west northwest of Puu O Keokeo on the southwest rift zone of Mauna Loa. From the intersection of Highway 11 and South Point Road, drive 20.5 miles west to reach a locked gate to the Yee Hop Ranch on the right side (0.2 mile after mile marker 90). Turn right on to a 4-wheel drive dirt road and go 1.1 miles to reach a road on the left (just before the ruins of an ohia mill). Turn left and go 5.0 miles to reach the YEE HOP #4 station (1.3 miles after the ruins of the koa mill).

note: see page 51 for access information (Yee Hop Ranch).



HUALALAI DRYTILT STATIONS

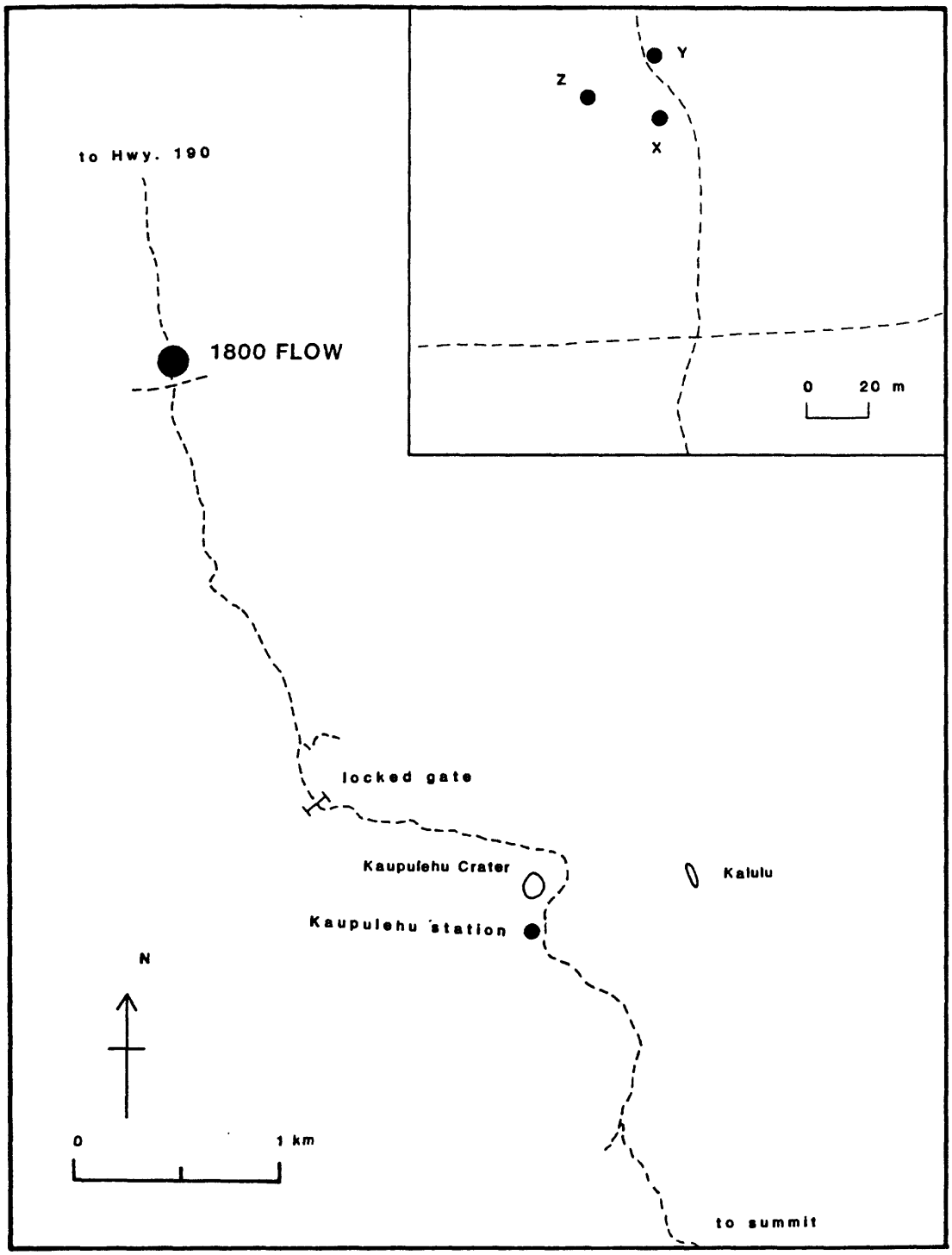

DRYTILT STATIONS ON HUALALAI, HAWAII
Hwy. 19
Hwy. 190
Northwest
Rift
Zone
Puu Waawaa
1800 FLOW
KAUPULEHU
Hualalai Summit
KIPAHEE
MALEKULE
NEW PUUHALE
MOORE CRATER
PIHAPONO
WAHAPELE
KANEKII
Hwy. 190
Hwy. 180
Hwy. 11
Kailua, Kona
Pacific Ocean
2 KM
19° 45'
19° 30'
LATITUDE
156° 05'
LONGITUDE
155° 45'

1800 FLOW (8/2/84 to present)

PREVIOUS NAME : None
MAP COORDINATES : N 19 44.50' W155 55.64' Kailua
STATION DATA : Ly = 21.06 m, Lz = 23.68 m, Theta = 93.0, Phi = 163.0
STATION EQUATION : T(n) = 0.483 d(Y-X) + 0.024 d(X-Z)
T(e) = 0.148 d(Y-X) + 0.449 d(X-Z)

1800 FLOW station is located approximately 3.1 km north-northwest of Kaupulehu Crater on the northwest rift zone of Hualalai. From the KAUPULEHU station, go 1.0 mile to reach a locked gate. Continue on through the gate for 1.4 miles to reach an intersection. Continue on throught the intersection for 0.1 mile to reach the 1800 FLOW station. The station is just before an unlocked gate.

note: see page 51 for access information (Bishop Estate).

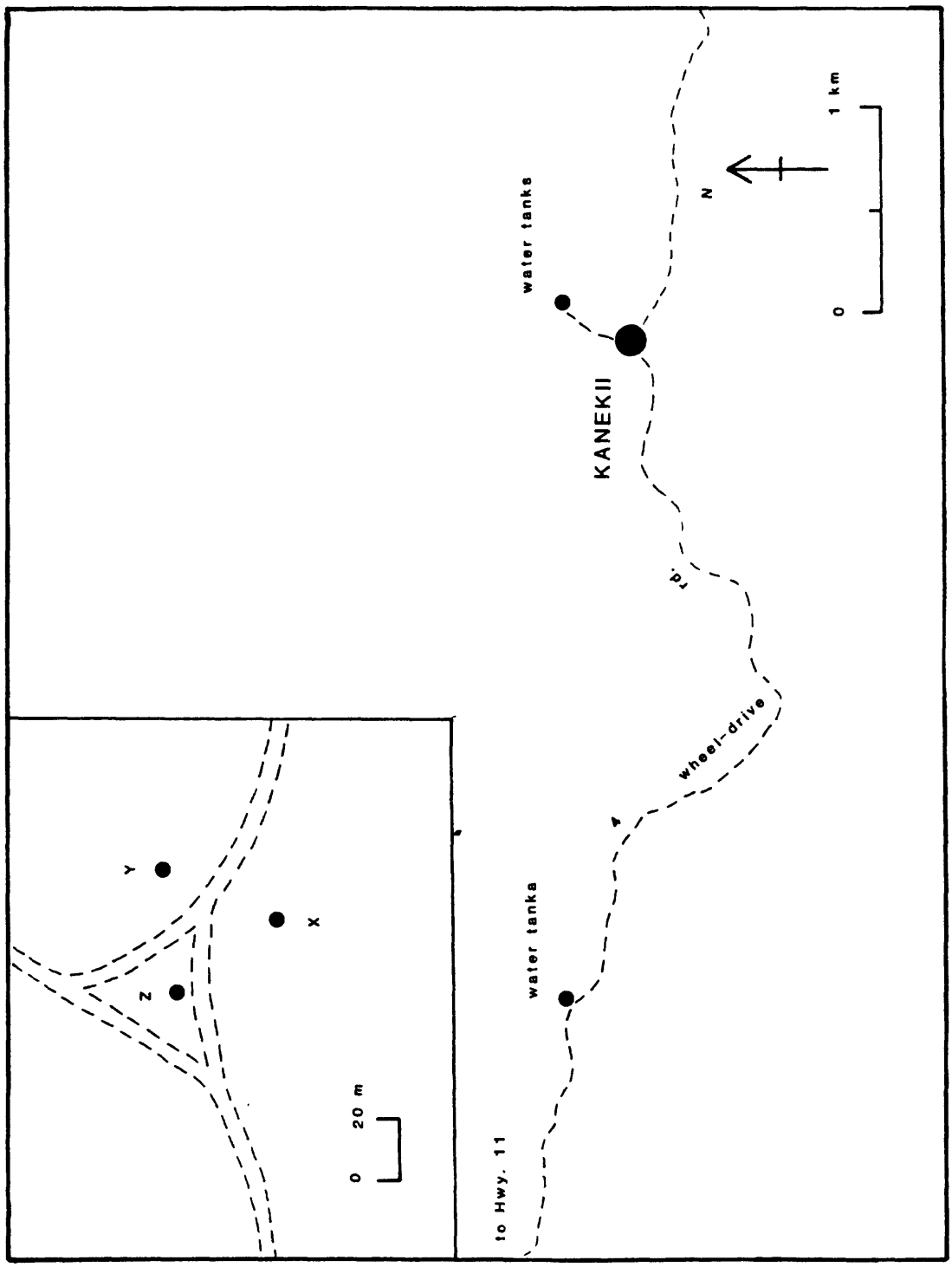


KANEKII (6/3/76 to present)

PREVIOUS NAME : None
MAP COORDINATES : N 19 30.39' W155 45.93' Puu Lehua
STATION DATA : Ly = 40.00 m, Lz = 40.00 m, Theta = 66.0, Phi = 126.0
STATION EQUATION : T(n) = 0.170 d(Y-X) − 0.117 d(X-Z)
T(e) = 0.234 d(Y-X) + 0.264 d(X-Z)

KANEKII station is located on private ranch land approximately 16.3 km east-northeast of Captain Cook town on the west side of Mauna Loa. From the intersection of Hwy. 11 and Hwy. 160 (at Captain Cook), go 1.1 miles southeast on Hwy. 11 (past the Kealakekua Ranch Center) to reach Koa Road on the left side. Turn left and go 10.9 miles to reach the KANEKII station. It is recommended that the Hoanuanu, Kealakekua, and Puu Lehua quadarangle maps be taken along to prevent taking the wrong forks and turnoffs.

note: see page 51 for access information (Greenwell Ranch).

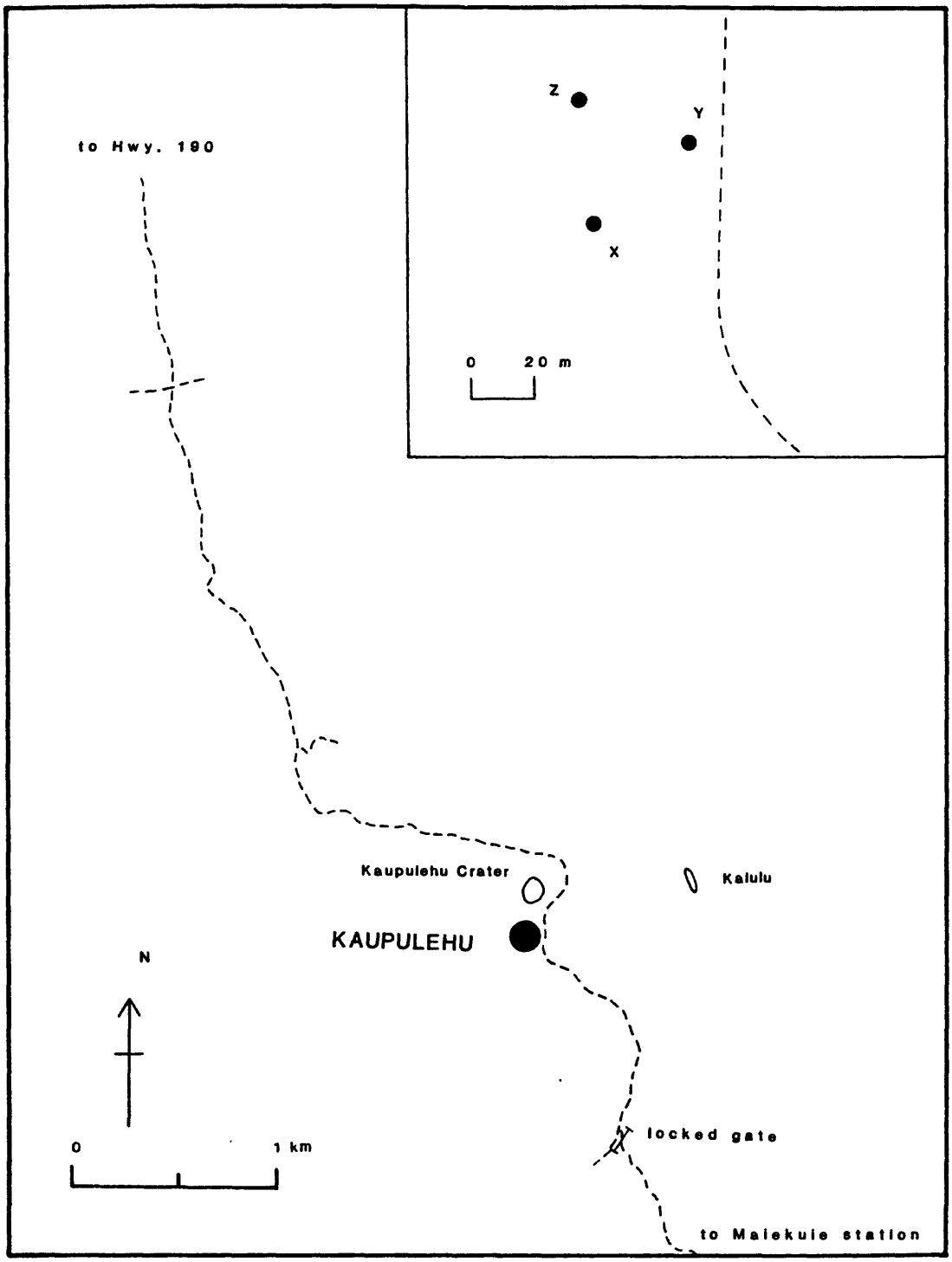


KAUPULEHU (11/7/86 to present)

PREVIOUS NAME :	None
MAP COORDINATES :	N 19 42.98' W155 54.61' Kailua
STATION DATA :	Ly = 39.59 m, Lz = 39.90 m, Theta = 41.0, Phi = 98.0
STATION EQUATION :	T(n) = 0.042 d(Y-X) — 0.226 d(X-Z)
	T(e) = 0.298 d(Y-X) + 0.196 d(X-Z)

KAUPULEHU station is located approximately 250 m south of Kaupulehu Crater on the northwest rift zone of Hualalai. From the MALEKULE station, go 2.0 miles to reach a locked gate (just after the sheep station). Go through the gate and take the right fork. Go 0.8 mile to reach the KAUPULEHU station.

note: see page 51 for access information (Bishop Estate).

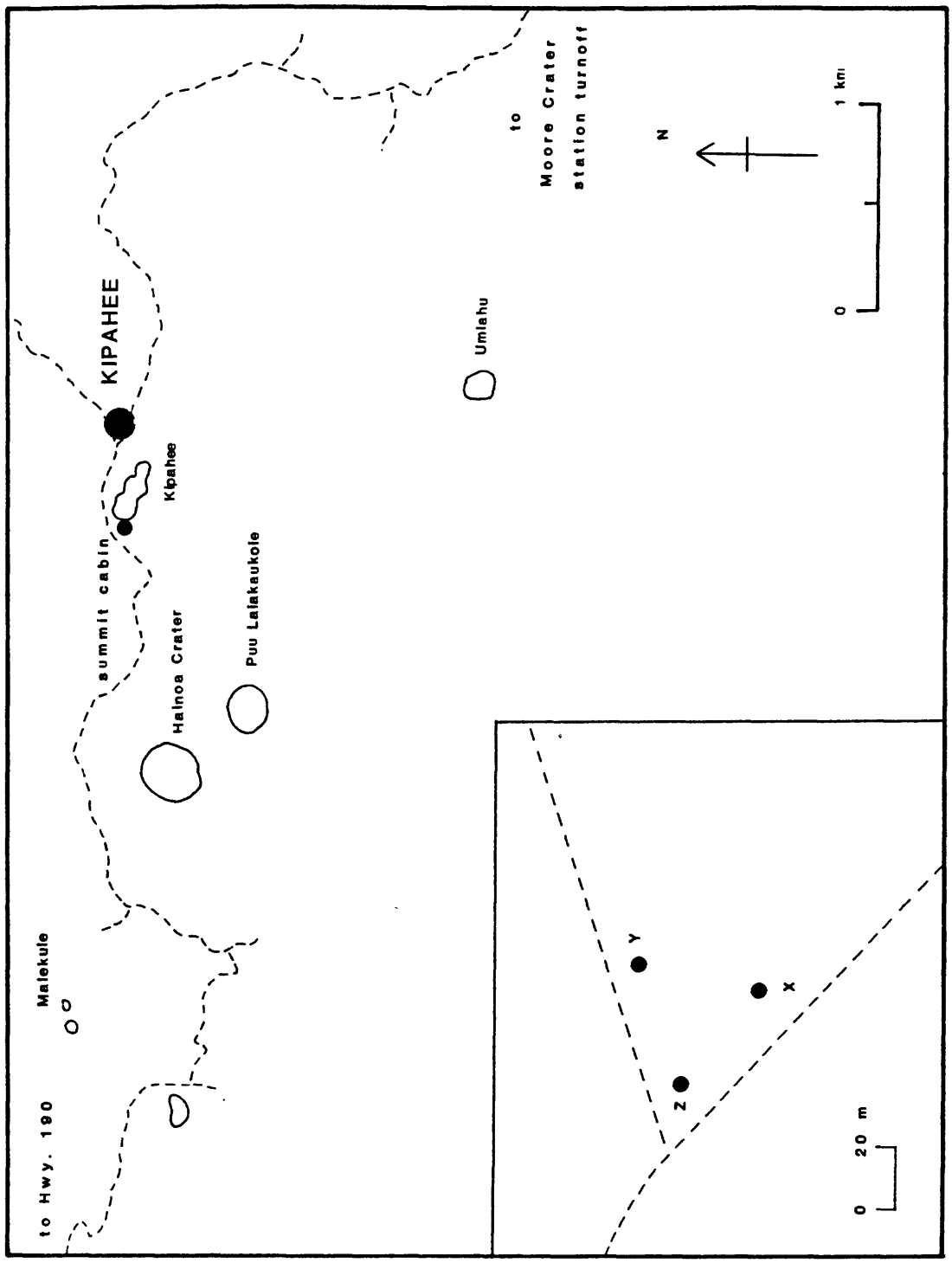


KIPAHEE (6/21/85 to present)

PREVIOUS NAME :	None
MAP COORDINATES :	N 19 41.78' W155 51.26' Hualalai
STATION DATA :	Ly = 40.02 m, Lz = 39.62 m, Theta = 78.0, Phi = 140.0
STATION EQUATION :	T(n) = 0.217 d(Y-X) — 0.059 d(X-Z)
	T(e) = 0.182 d(Y-X) + 0.280 d(X-Z)

KIPAHEE station is located approximately 300 m west of Kipahee Crater on the summit of Hualalai. From the turnoff to the MOORE CRATER station, go 3.0 miles to reach a fork in the road. Continue to the right and go 0.4 mile to reach another fork. Continue to the left and go 2.0 miles to reach a dirt road on the right side and the KIPAHEE station (located 0.3 mile before the road to the summit cabin).

note: see page 51 for access information (Bishop Estate).

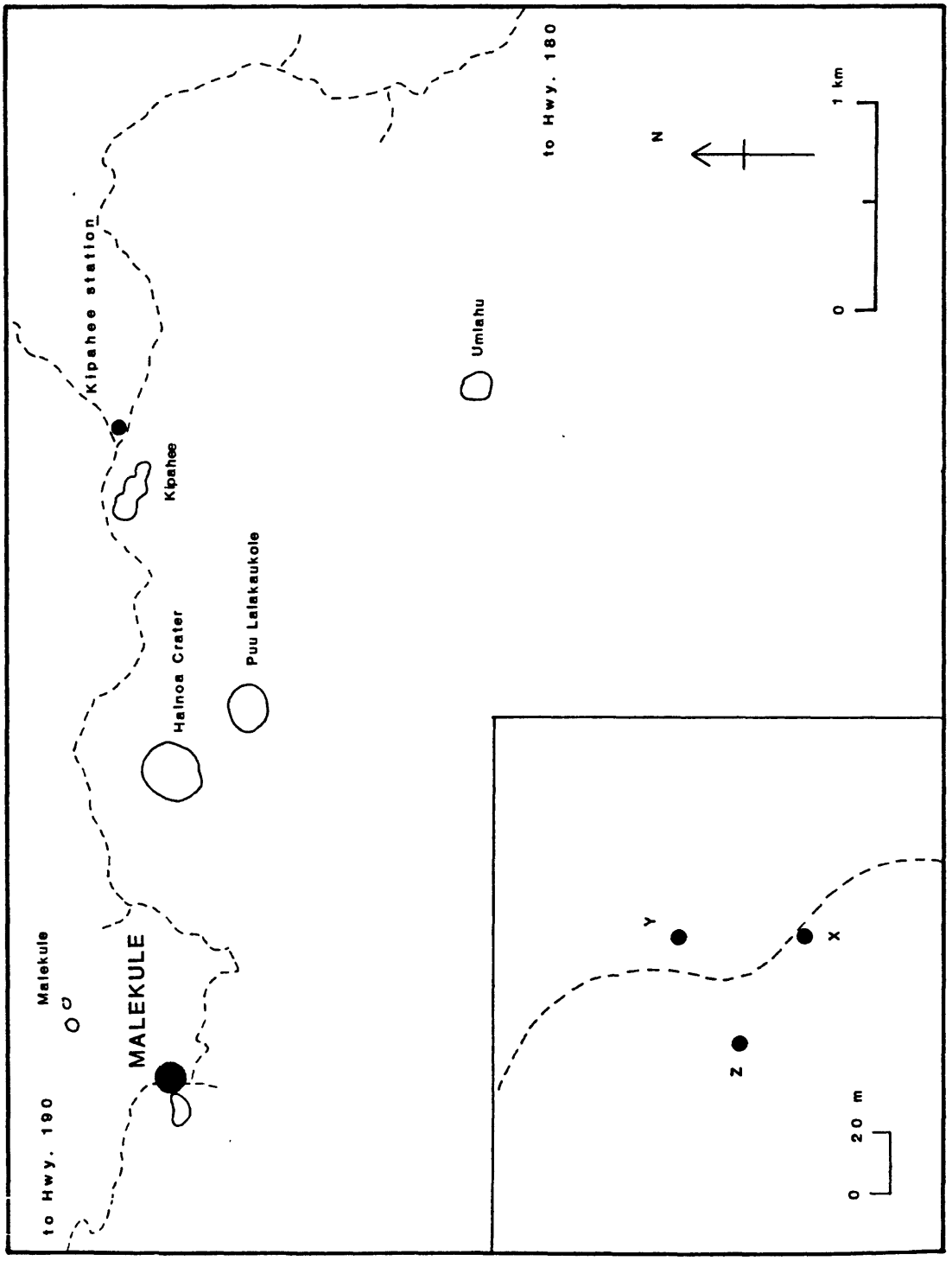


MALEKULE (6/21/85 to present)

PREVIOUS NAME : None
MAP COORDINATES : N 19 41.63' W155 53.06' Kailua
STATION DATA : Ly = 40.39 m, Lz = 40.17 m, Theta = 90.0, Phi = 149.0
STATION EQUATION : T(n) = 0.248 d(Y-X)
T(e) = 0.149 d(Y-X) + 0.290 d(X-Z)

MALEKULE station is located approximately 600 m southwest of Malekule on the northwest rift zone of Hualalai. From the KIPAHEE station, go 1.7 miles to reach a fork in the road. Turn left and go 0.8 mile to reach another fork. Turn right and go 320 m to reach the MALEKULE station.

note: see page 51 for access information (Bishop Estate).

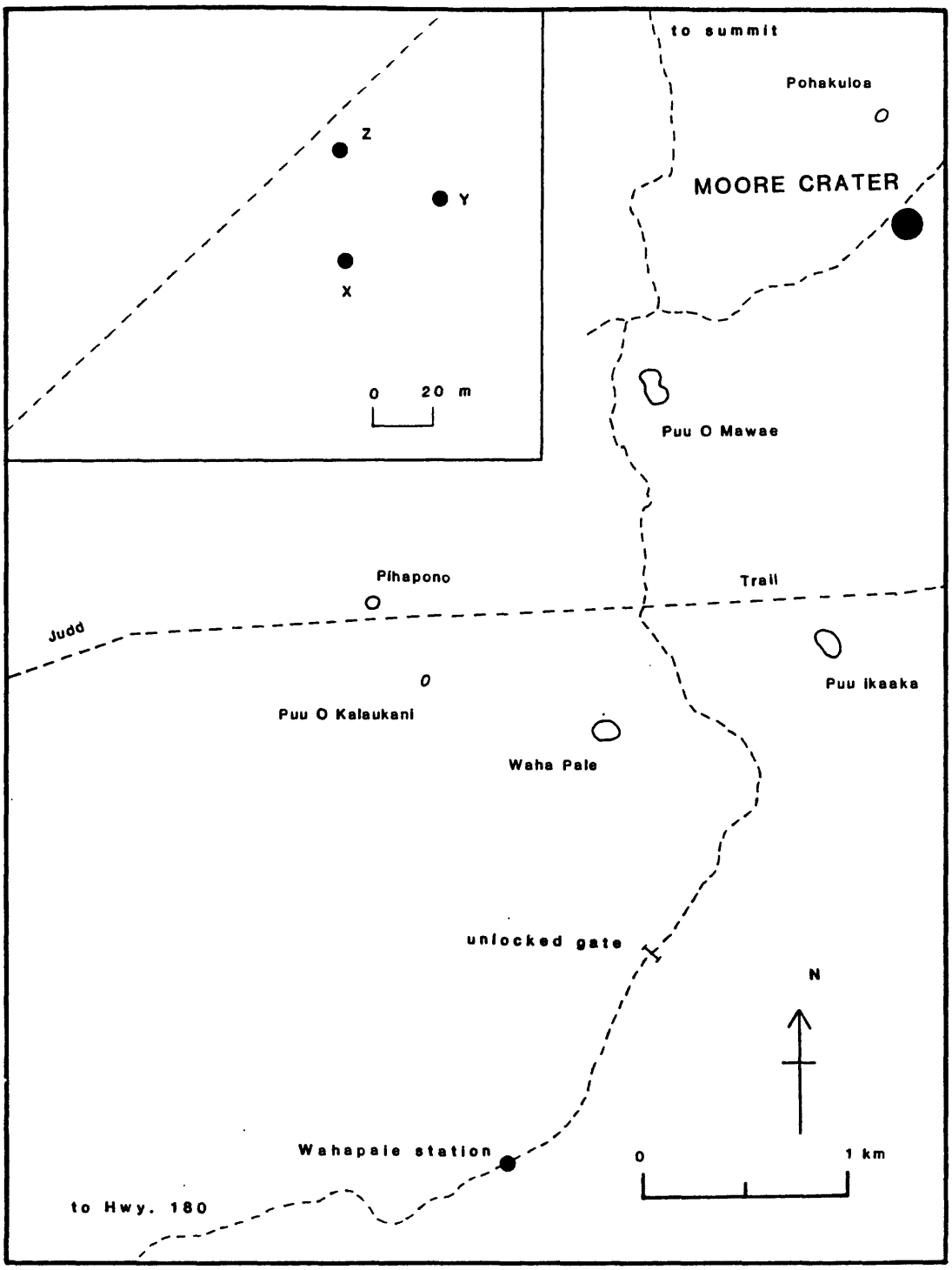


MOORE CRATER (8/1/84 to present)

PREVIOUS NAME :	None
MAP COORDINATES :	N 19 39.08' W155 48.99' Hualalai
STATION DATA :	Ly = 36.45 m, Lz = 36.45 m, Theta = 34.0, Phi = 93.0
STATION EQUATION :	T(n) = 0.017 d(Y-X) — 0.265 d(X-Z)
	T(e) = 0.320 d(Y-X) + 0.179 d(X-Z)

MOORE CRATER station is located approximately 2.1 km north-northeast of Puu Ikaaka on the southeast flank of Hualalai. From the WAHAPELE station, go 0.7 mile to reach an unlocked gate. Continue on through this gate for 2.3 miles to reach a dirt road on the right side (0.3 mile north of Puu O Mawae). Turn right and go 0.9 mile across a flat, sandy area to reach the MOORE CRATER station.

note: see page 51 for access information (Bishop Estate).

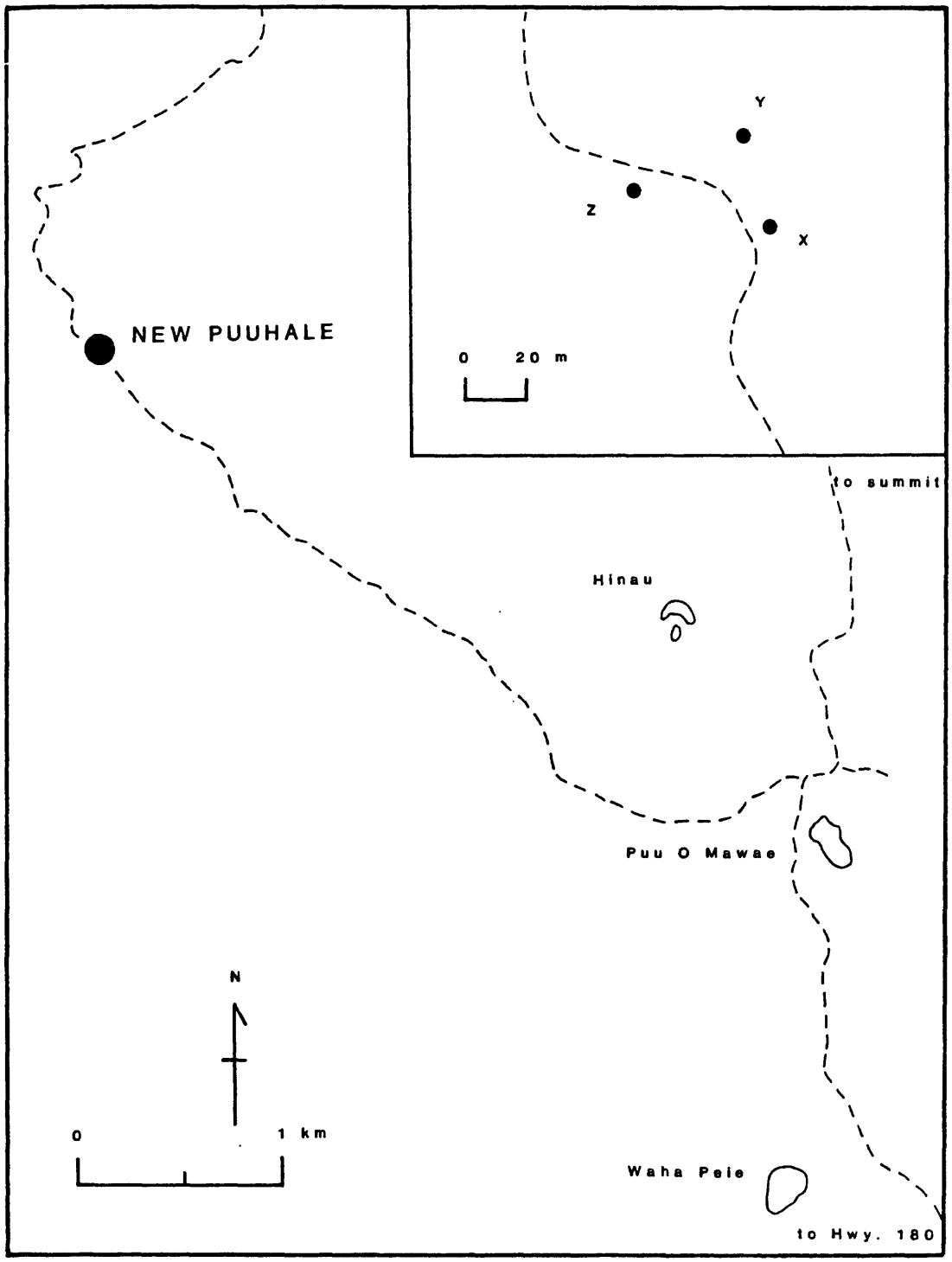


NEW PUUHALE (6/19/85 to present)

PREVIOUS NAME : PUUHALE (8/1/84 to 6/19/85)
MAP COORDINATES : N 19 39.91' W155 51.76' Hualalai
STATION DATA : Ly = 33.92 m, Lz = 44.81 m, Theta = 110.0, Phi = 165.0
STATION EQUATION : T(n) = 0.348 d(Y-X) + 0.093 d(X-Z)
T(e) = 0.093 d(Y-X) + 0.256 d(X-Z)

NEW PUUHALE station is located approximately 4.3 km northwest of Puu O Mawae on the southeast flank of Hualalai. From the WAHAPELE station, go 0.7 mile to reach an unlocked gate. Continue on through this gate for 2.2 miles to reach a dirt road on the left (approximately 0.2 mile past Puu O Mawae). Turn left and go 3.3 miles to reach the NEW PUUHALE station.

note: see page 51 for access information (Bishop Estate).

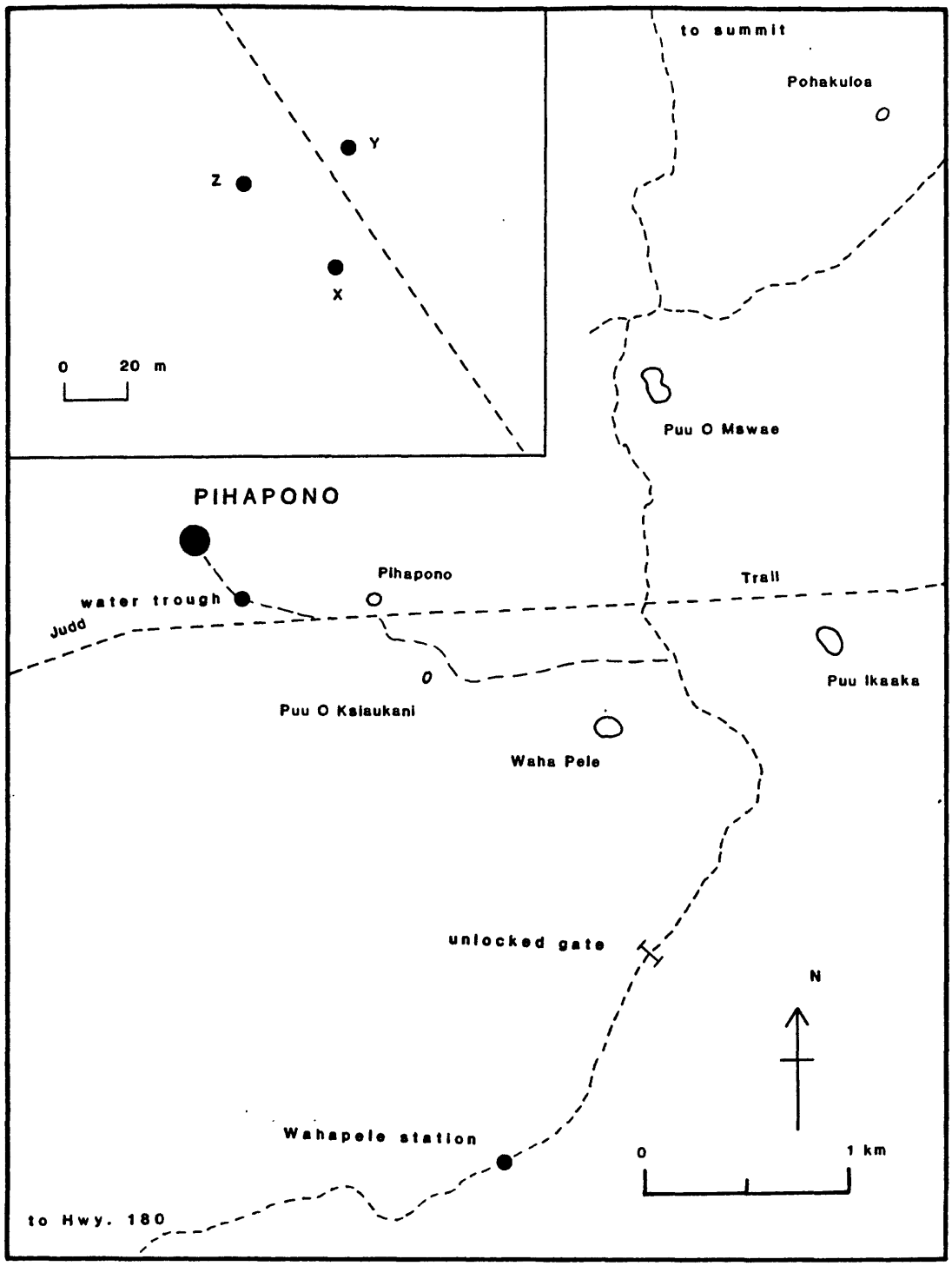


PIHAPONO (6/19/85 to present)

PREVIOUS NAME : None
MAP COORDINATES : N 19 38.08' W155 50.90' Hualalai
STATION DATA : Ly = 36.88 m, Lz = 40.05 m, Theta = 85.0, Phi = 138.0
STATION EQUATION : T(n) = 0.252 d(Y-X) − 0.027 d(X-Z)
T(e) = 0.227 d(Y-X) + 0.312 d(X-Z)

PIHAPONO station is located approximately 800 m west of Pihapono on the southeast flank of Hualalai. From the WAHAPELE station, go 0.7 mile to reach an unlocked gate. Continue on through this gate for 1.4 miles to reach a dirt road on the left (along an experimental tree planting plot). Turn left and go 1.7 miles (paralleling the Judd Trail) to reach a cattle water trough. Turn right and go 0.25 mile to reach the PIHAPONO station.

note: see page 51 for access information (Bishop Estate).

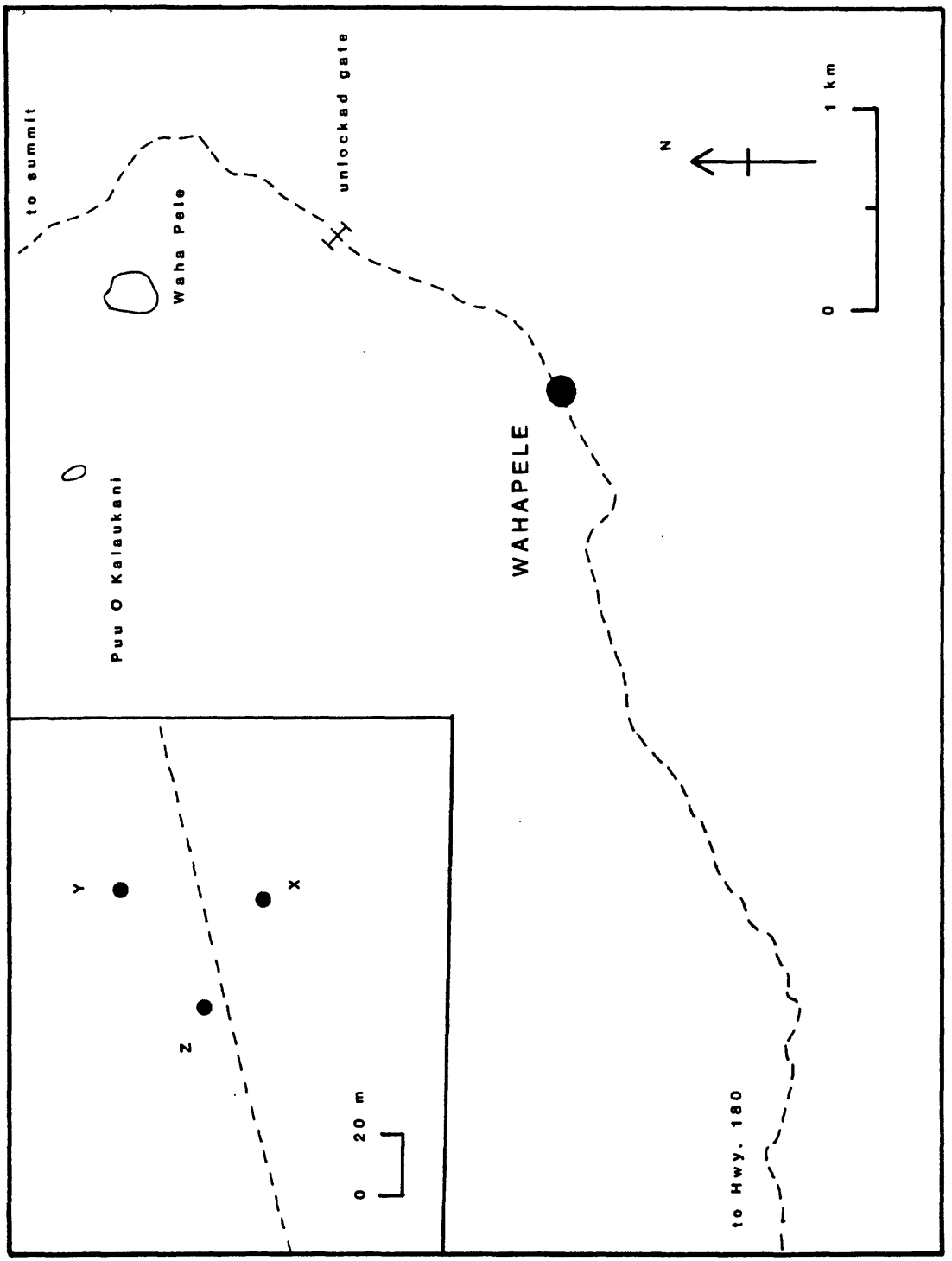


WAHAPELE (7/31/84 to present)

PREVIOUS NAME : None
MAP COORDINATES : N 19 36.66' W155 49.90' Puu Lehua
STATION DATA : Ly = 42.70 m, Lz = 38.89 m, Theta = 85.0, Phi = 152.0
STATION EQUATION : T(n) = 0.225 d(Y-X) — 0.024 d(X-Z)
T(e) = 0.119 d(Y-X) + 0.278 d(X-Z)

WAHAPELE station is located approximately 6.2 km northwest of Puu Lehua on the southeast flank of Hualalai. From the intersection of Donkey Mill Road and Highway 180, go 0.7 mile east-northeast to reach 4-wheel drive dirt road on the right with a locked gate. Turn right and go 0.65 mile to reach a locked gate. Continue on through the gate for 3 miles to reach another locked gate. Continue on through this gate 4.7 miles to reach the WAHAPELE station.

note: see page 51 for access information (Bishop Estate).



STATION ACCESS INFORMATION

All of the telephone numbers listed below are current as of May, 1987. Along with getting permission from the land owners or managers to enter their property, one should make arrangements to obtain any key(s) that may be needed.

Bishop Estate (office)	322-6088
Greenwell Ranch (office)	323-2862
Kahuku Ranch (foreman's house)	929-7227
Kapapala Ranch (ranch house)	928-8403
(Mrs. Cran's office)	961-4781
Kulani Prison (office)	935-3758
Pohakuloa Military Training Area	969-2400
Yee Hop Ranch (Jim Kiyabu- manager)	328-2498

STATION INDEX