MILLIMETER ARRAY
MEMO NO. 47

Feb. 21,1988

HIGH SITE MILLIMETER ARRAY CONFIGURATIONS

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I. Old and New Concepts

Earlier work on configurations for the millimeter array (MMA) assumed the antennas were 10 meters in diameter (D) and concluded that there would be adequate imaging quality if the number of antennas, N, was ≥ 21. The main conclusions of the configuration studies were: the most compact, 90 m configuration should be in the form of a packed circle with antennas at random locations inside the circle; the best configurations for uniform sampling at all spacings between 2D and the configuration "diameter" were circles (or ellipses for low declination work) with antennas at randomized locations on the circumference of the circles; and the best configurations for enhanced sensitivity at the shorter spacings were VLA-like Y's. Both circular and the VLA-like Y configurations were deemed to have good imaging properties, so the choice between the two depended upon the desired distribution of sensitivity in the u-v plane. The first chapter of Volume I of the MMA design study summarizes these results.

Volume II of the MMA design study evolved the MMA concept by emphasizing the importance of "high sites" greater than 9000 feet in altitude, and also changed the paradigm array to 40 antennas with diameters of 7.5 meters. The Volume I concept included configurations as large as 30-40 km, whereas the Volume II concept allows for restriction to ≤ 3 km if this is necessary to get the most desirable high altitude site.

The newer concept may require three changes in our approach to the MMA configurations. The first and most important is the possible need to adopt non-ideal configurations because of the limitations of the topography of particular high sites; the second is the need to allow for the difficulty of placing 40 antennas, 7.5 m in diameter, in a 300 m VLA-like Y; and the third is the need for excellent imaging quality for short tracking periods - which can be a problem for Y-shaped arrays. As we will discuss in this memo the latter two problems are easily solved by replacing the VLA-like Y, with antennas at radial distances proportional to $n^{1.728}$, by an array with a larger (5 or 7) number of arms with the same radial distribution. For high sites without the ideal large flat plateaus, the nature of the topography dictates that one

consider array configurations tailored to the site.

II. New Ideal Configurations

In this memo we will assume that the packed circle shown in Figure 1a (or ellipse with 3:1 North-South elongation) can always be achieved for the 90 m configuration. We also assume that the circular configurations are most desireable for the other $\leq$ 3 km arrays. Hence flat plateaus $\geq$ 3 km in size, or $\geq$ 3 km East-West and 9 km N-S are most ideal. However, high altitude is so important that non-ideal configurations tailored to the topography may be acceptable. This requires us to consider configurations tailored to the possibilities of each non-ideal site. A schematic example of antennas and an accompanying road system for a non-ideal site is shown in Figure 1b.

A critical assumption affecting the acceptability of configurations is the maximum tracking time allowed to obtain complete u-v converage. We will adopt, as a standard for the purposes of this memo, tracking over hour angles of $\pm 2^h$.

If VLA-like radial distributions of antennas are deemed desireable, both the problem of packing 40 antennas in 300 m and the four hour limit in tracking time forces one to consider more than three arms. An odd number of arms is desireable in order to place each arm at a different angle, and the larger the number of arms the fewer number of antennas per arm. The final result is that the best radial configuration consists of five arms with eight antennas on each arm. In Figure 2 we show 40 antennas on five arms. Figure 2a shows the antenna locations; Figure 2b shows the u-v plane sampling for snapshots of a source at 60° declination observed at the zenith; and Figure 2c shows $\pm 2^h$ hour angle tracking for the same declination.

In principle, the ~ 3:1 N-S elongation needed for low declinations is achievable for the five-armed configuration by elongating either one arm pointed to the north or south, or two of the most northerly or southerly arms.

Both three- and five-armed arrays deserve serious consideration if it is acceptable to have six and four hour tracking, respectively. As we will see, "warped" versions of arrays like this can occur for some of the topography limited arrays required by certain high sites.

Let us now consider six of the sites that have been discussed for the MMA, all of which allow configurations at altitudes above 9000 feet.

III. Three Sites Allowing Ideal Configurations

Ignoring other considerations, there are three sites under current discussion in which any of the ideal configurations can be placed.

On the Aquarius Plateau in Utah there is an area in which there are attainable circular configurations up to 10 km and radial configurations up to 18 km. The Grand Mesa in Colorado allows, at least based upon the topographic maps, many locations for 3 km arrays and a few 3 X 9 km arrays. In principle the topography of the Grand Mesa plateau might allow up to a 22 km three-armed array. The South Park valley in Colorado, located about a 1.5 hour drive from both Denver and Colorado Springs, has a number of locations, based only on considerations of topography, on which $\geq$ 3 km and $\geq$ 3 X 9 km arrays can be placed, with up to 15 km arrays being possible in principle. Figues 3, 4, and 5 show attempts to compress the topographic maps of each of these sites onto one page.

IV. Topography-Limited Sites

Mauna Kea in Hawaii is probably the best high site in the U.S. for optically, infra-red, and mm wavelength astronomy. At 13000-14000 ft, its altitude is ideal, but the potential for the desired configurations is very limited. Figures 6 and 7 show displays of the topography of Mauna Kea and in Figure 7 we have used only topographic considerations to lay out potential configurations. The largest configurations that might have acceptable imaging characteristics are three-armed radial configurations 500-700 m in size. Figure 8 shows the antenna locations, snapshot u-v plane, and four hour tracking u-v coverage (for a source at a declinations of 60^{0}) for a 500 m, nearly symmetrical configuration that may be allowed by the topography of Mauna Kea. Configurations much larger than than this do not seem to be reasonable, and even these size scales are difficult to achieve.

The next highest site that we have evaluated, at an altitude of 10600 ft, is the South Baldy site near Socorro. Figure 9 shows the topography of this site. There are a number of locations for 90 and 300 meter configurations, and the N-S ridges allow a reasonable degree of N-S elongation. It is easy, based only on considerations of topography, to place a 1 km, three-armed radial configuration on this site. In addition, there are two possibilities that have been identified for topography-limited configurations that are 2.5 and 3.5 km

in size. Figure 10 (a,c,e) shows a 3.5 km configuration that is possible if antennas can be place at all locations on the S. Baldy ridge and the ridge on which Timber peak is located. However, because of the facilities already on the S. Baldy ridges and the environmental impact problems of the Timber Peak ridge, it may be necessary to avoid these areas. In Figure 10 (b,d,f) there is a 2.5 km configuration in which antennas form one arm of a distorted Y along the east side of the road along S. Baldy ridge, antennas are placed in a E-W arm on potentially accessible sites along the present access road to the top, and the third "arm" extends along ridges north of S. Baldy. These two large arrays have not been optimized with regard to each antenna location, so the u-v plane coverages contain some some holes and concentrations that can be fixed up; however, the large scale geometric limitations of the South Baldy ridges are reasonably well delineated by Figure 10.

A third site that is slightly limited by topography is at Sacramento Peak in New Mexico. A relatively flat area, at latitudes just above 9000 ft, lies just east of the western ridge where there are a number of optical telescopes including the National Solar Observatory instruments. The topography of this area will allow, as shown in Figure 11, roughly 2 km circular arrays or roughly 2.5 km radial arrays. In Figure 12 we show the antenna locations, and two u-v plane diagrams, for a five-armed radial configuration in which the ridges allow a 2.5 km array.

V. Summary of Results and Work to Be Done

In this memo we have summarized some of the obvious changes in the configurations for the MMA that may follow from the change to a high site concept with arrays with size scales up to 3 km. The most important results are: the generalization of the VLA-like Y arrays to five-armed radial configurations; and the new focus on topography-limited configurations for some potential sites. We conclude that the sites on the Aquarius plateau, the Grand Mesa, and in the South Park valley allow theoretically ideal configurations that are 3 km (or much larger). We have also determined some of the topography-limited configurations that can be placed, solely on the basis of topographic consideration, on Mauna Kea, the ridges near South Baldy, and Sacramento Peak.

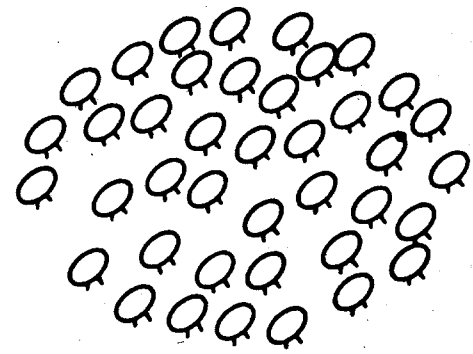
As has been previously known, the Mauna Kea area has extremely limited

possibilities for array sites. Even taking extreme liberty with the available topography, a roughly Y-shaped configuration 500 m in size is probably the largest that can be placed upon this site. Thus it is obvious that the price of utilizing Mauna Kea's excellent atmospheric properties would be a limitation to this size scale or less.

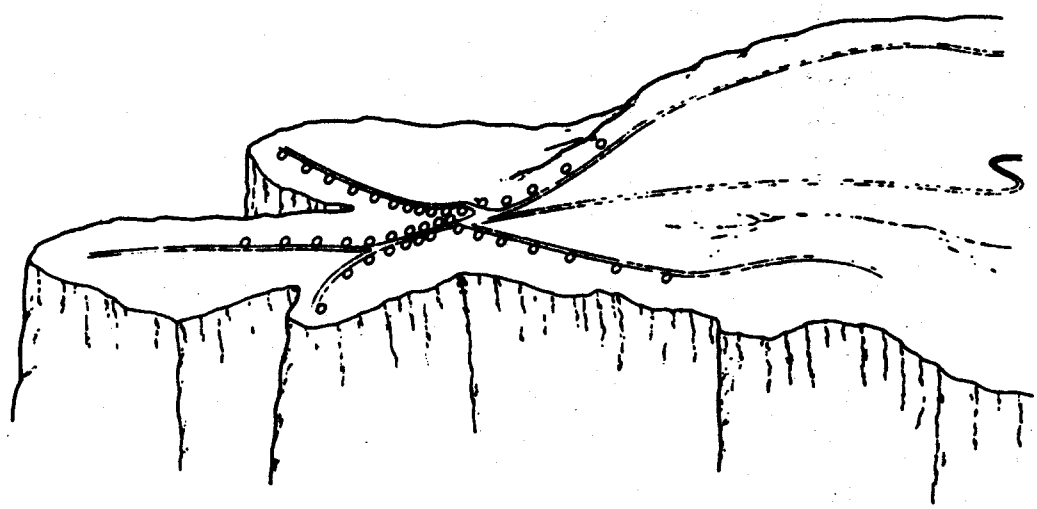
The ridges near South Baldy can, again based only on topographic considerations, allow ideal configurations up to a several hundred meters in size, and allow a good three-armed configuration 1° km in size. There are two possibilities for 2.5 and 3.5 km configurations utilizing potentially accessible ridges. These large configurations allow distorted versions of three-armed arrays, with the 3.5 km configuration probably being the most difficult to achieve because of potential conflict with present uses in one area, and because of environmental impact problems in another area.

The area east of the optical telescopes near Sacramento Peak can accomadate the ideal configurations for size scales up to 1 km and 1 X 2.5 km (N-S). A five-armed configuration with a size scale of 2.5 km, or circular arrays of about 2 km, are potentially achievable on this site.

For both these and other topography-limited sites it will be necessary to consider configurations based upon not only the topography, but also the practical limitations placed upon antenna locations because of prior use and environmental factors. Any of the topography-limited sites considered in this memo will require some degree of configuration re-design based upon other site considerations. Negotiation for the use of some sites will clearly be coupled with a need for configuration changes. Thus the array configuration problem for the MMA may require continuous work and re-evaluation. The acceptability of topography-limited configurations will be a continuing question for the scientific community. Thus one of the purposes of the present memo is to point out the relative lack of topographic limitations for the Aquarius Plateau, Grand Mesa, and South Park sites, while presenting an initial estimate of the arrays that may be possible on Mauna Kea, South Baldy, and Sacramento Peak. The latter arrays still require improvement in antenna locations, but this is worthwhile only if the gross geometry of configurations is deemed to be acceptable. The roughly 3 km requirement for the largest configurations would rule out Mauna Kea, but is close to being satisfied on both South Baldy and Sacramento Peak.

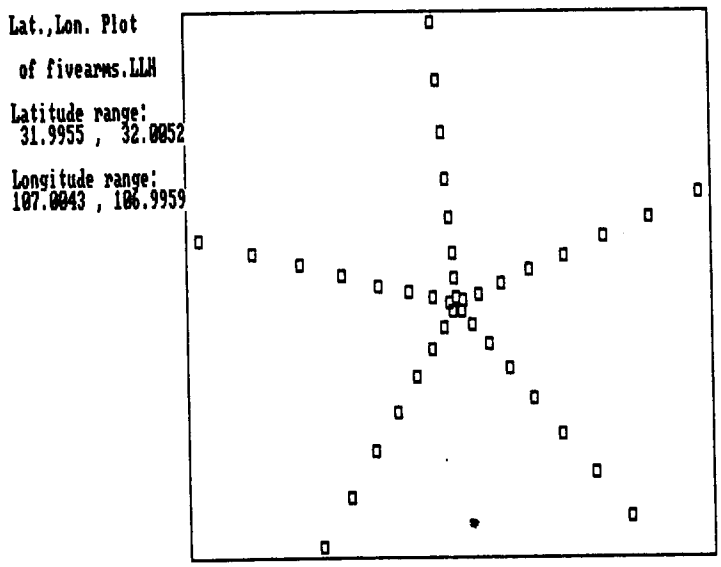


(a)



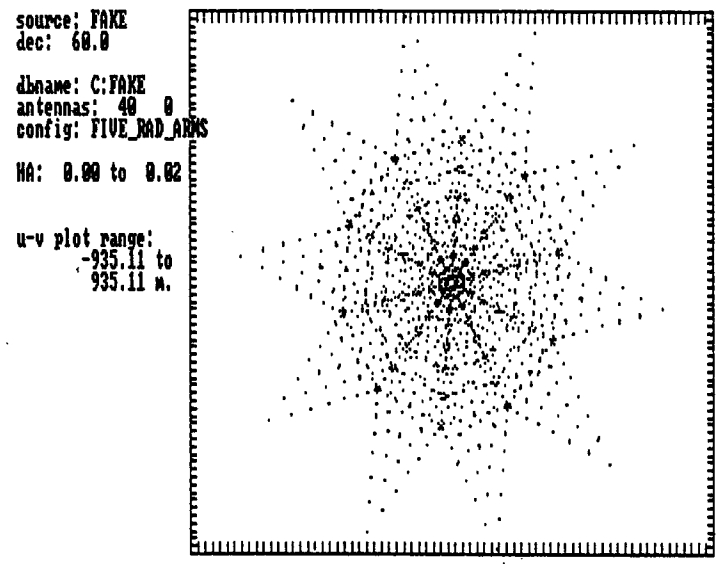
(b)

Figure 1. Examples of MMA configurations: (a) the most compact configuration for a fixed number of antennas, a packed circle/ellipse; (b) a schematic mountain-top array where topography significantly affects the larger 3 km, and possibly the 1 km, arrays.



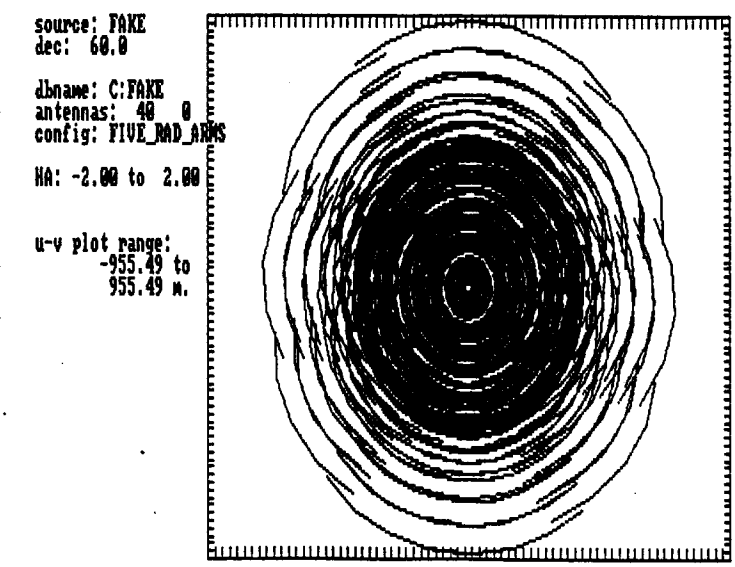
(a)

Five-Armed Array
Antenna Locations



(b)

Five-Armed Array
u-v Plane for
Snapshot



(c)

Five-Armed Array
u-v Plane for
Four Hour Tracking

Figure 2

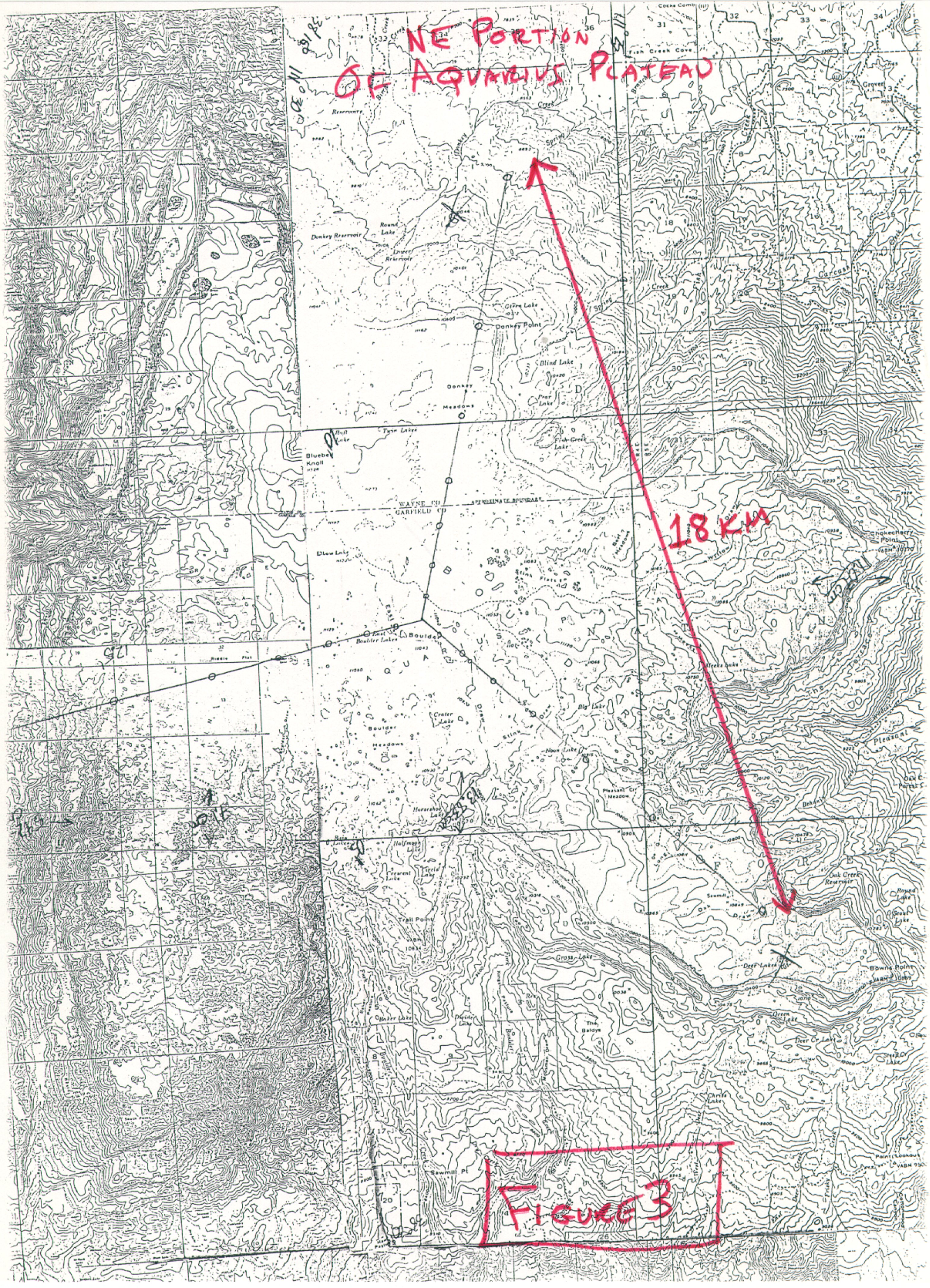

NE Portion
Of Aquarius Plateau
18 KM
Donkey Reservoir
Round Lake
Lower Reservoir
Green Lake
Donkey Point
Blind Lake
Donkey Meadows
Fish Creek Lake
Twin Lakes
Bluebell Knoll
WAYNE CO
GARFIELD CO
Elbow Lake
East Boulder Lakes
Boulder
Crater Lake
Boulder Meadows
Horseshoe Lake
Pleasant Cr Meadow
Noon Lake
Big Lake
Chokecherry Point
Oak Creek Reservoir
Bowns Point
Deep Lake
Cross Lake
The Baldys
Trail Point
Baker Lake
Sawmill Pt
Fish Creek Cove
Grover
Carcass
Pleasant

Figure 3

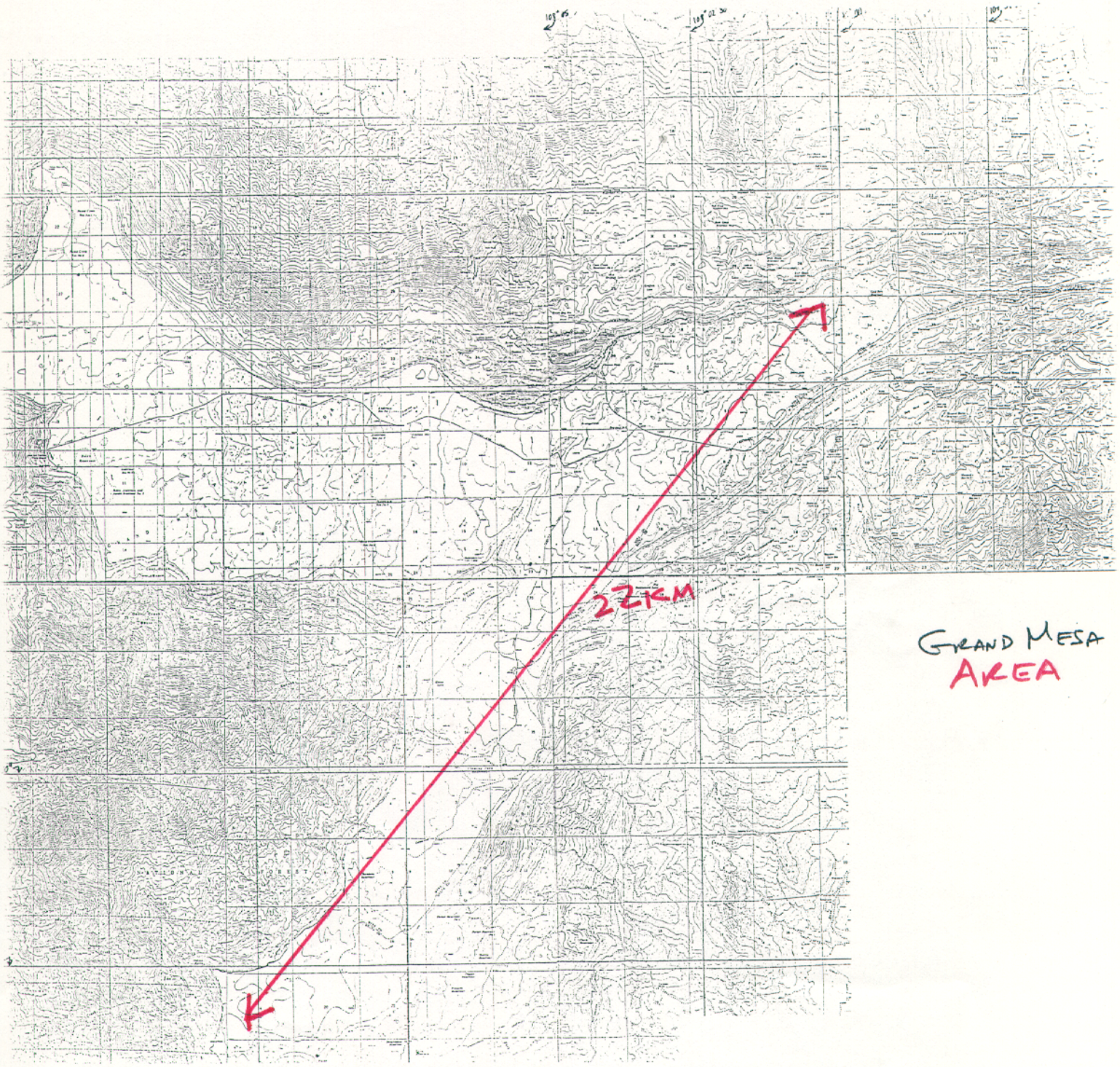


FIGURE 4

↑N

SOUTH PARK AREA

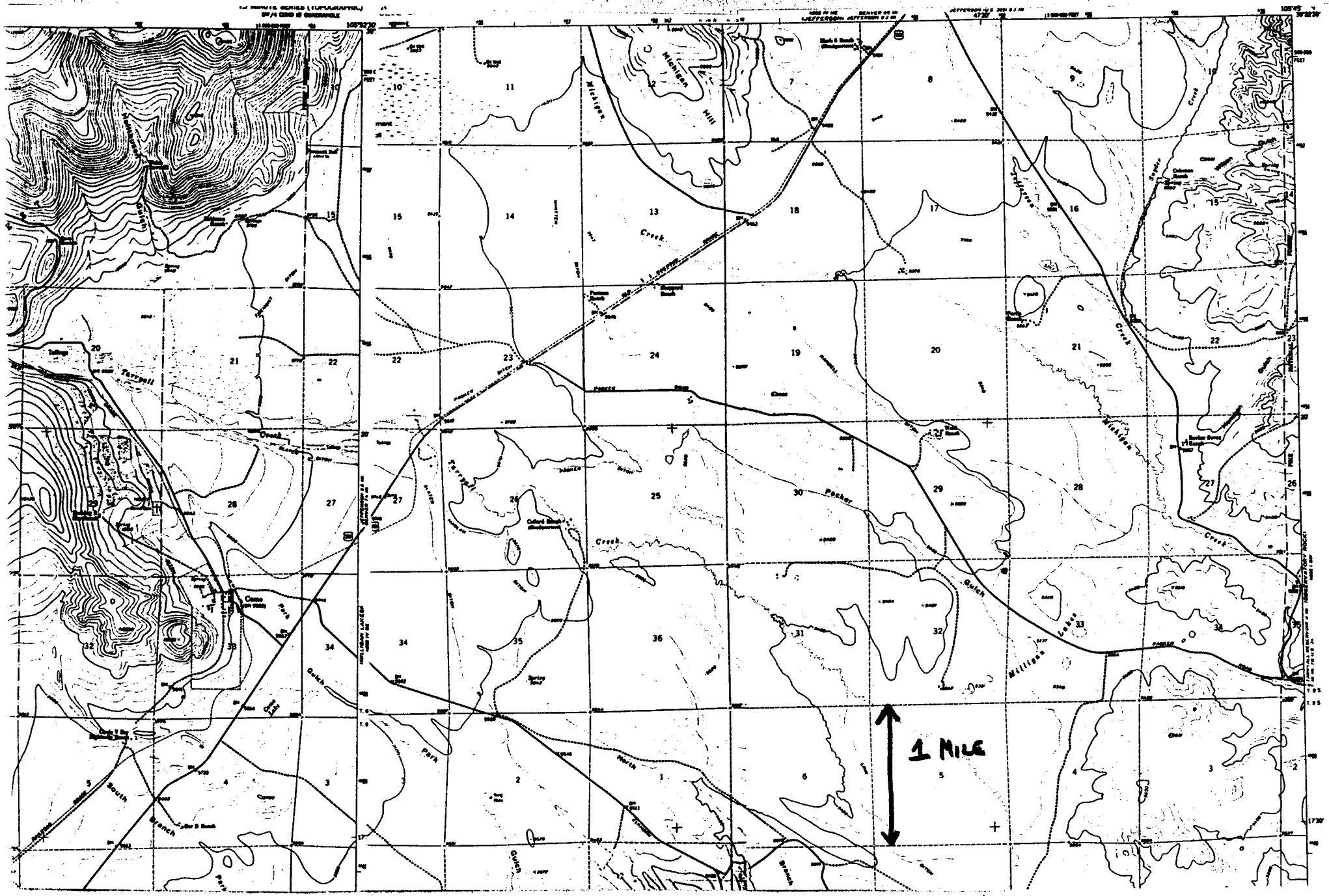


FIGURE 5

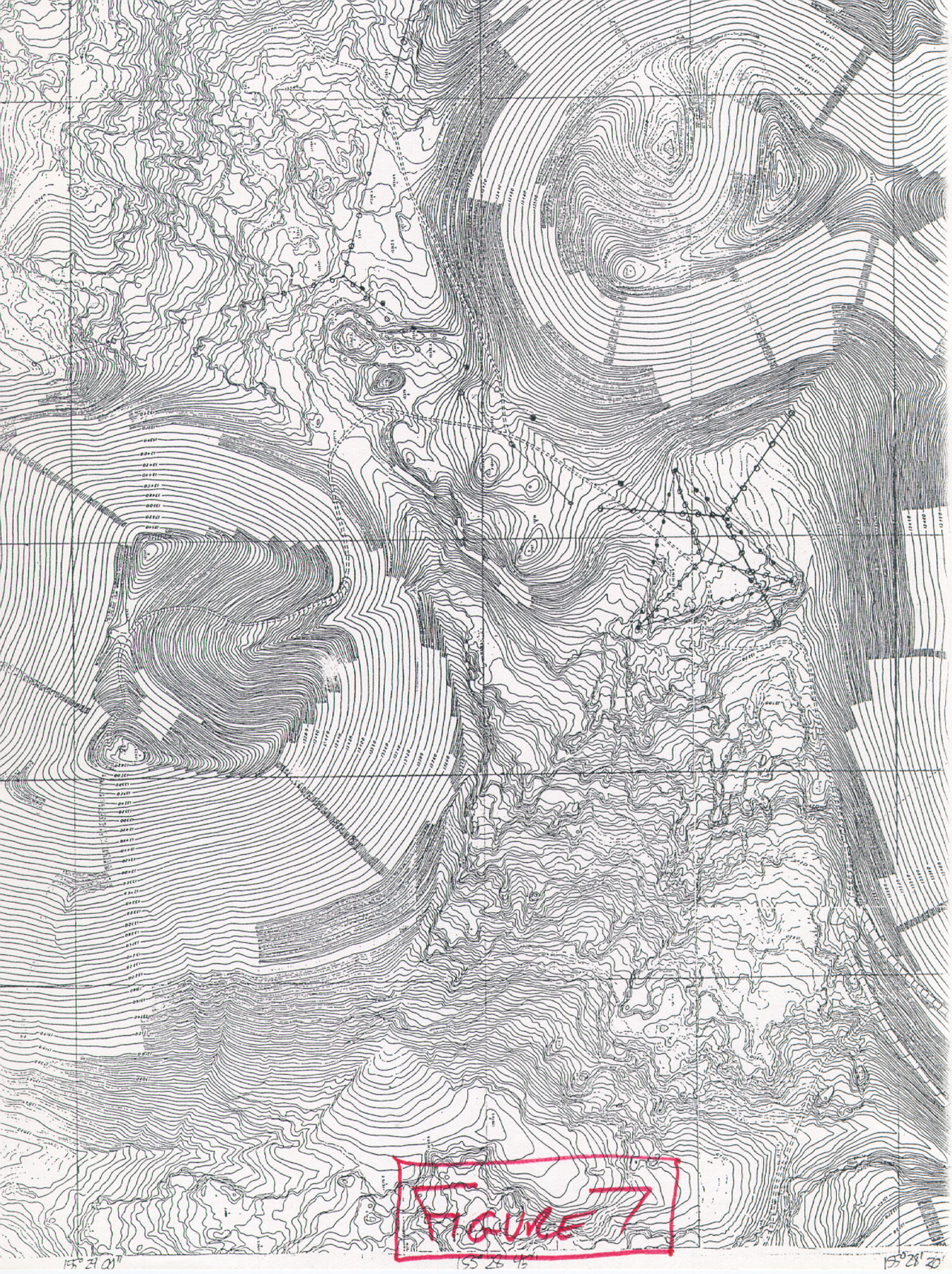
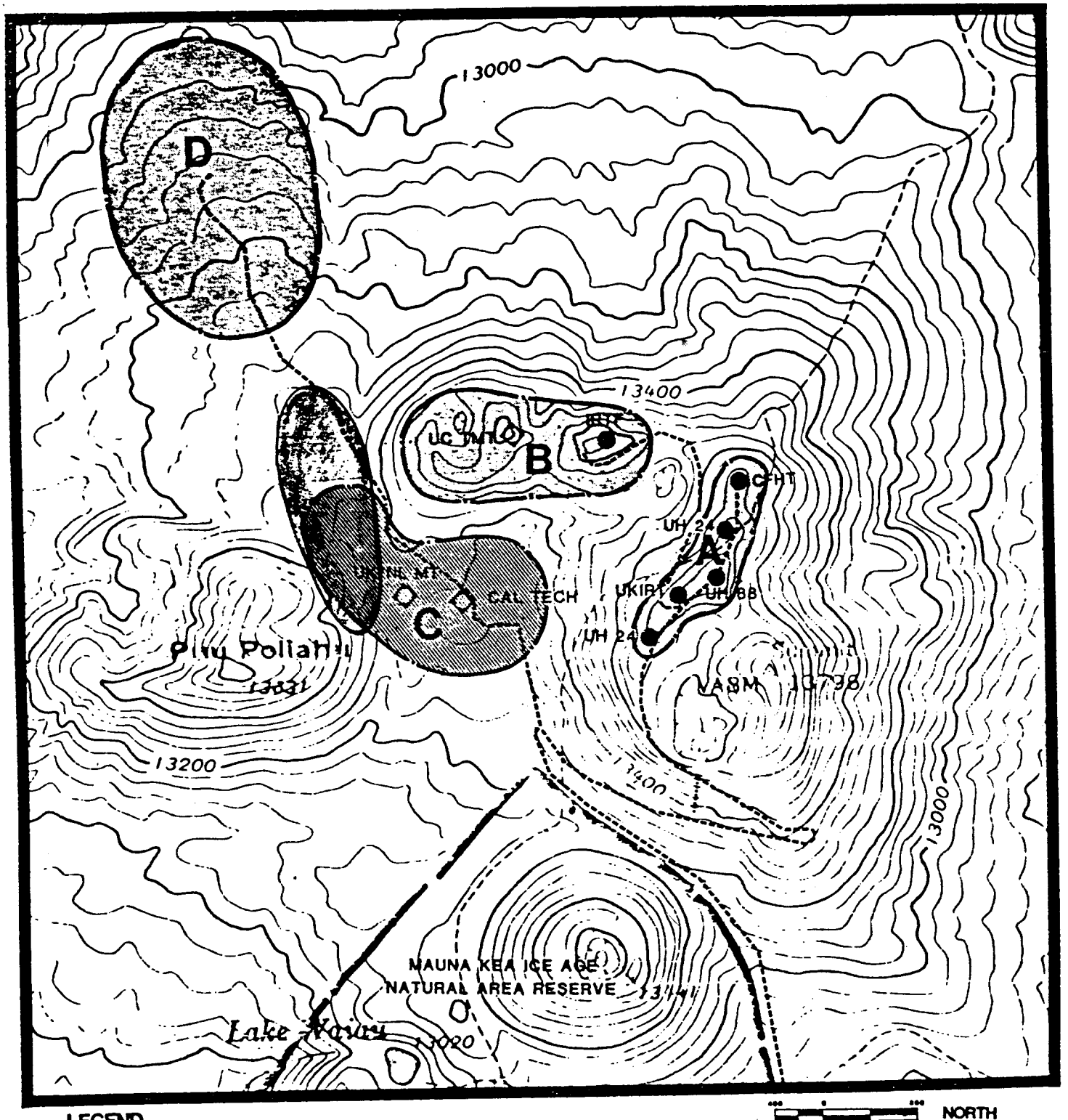


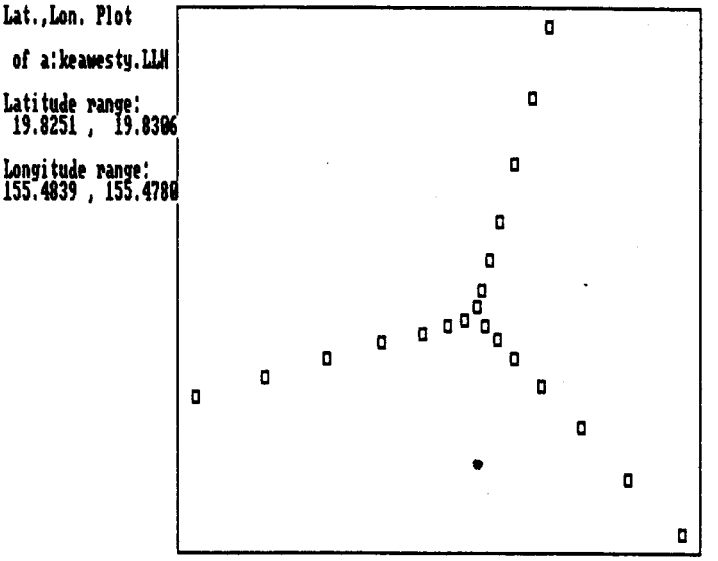
FIGURE 7
15° 27' 00"
15° 28' 40"
15° 28' 20"



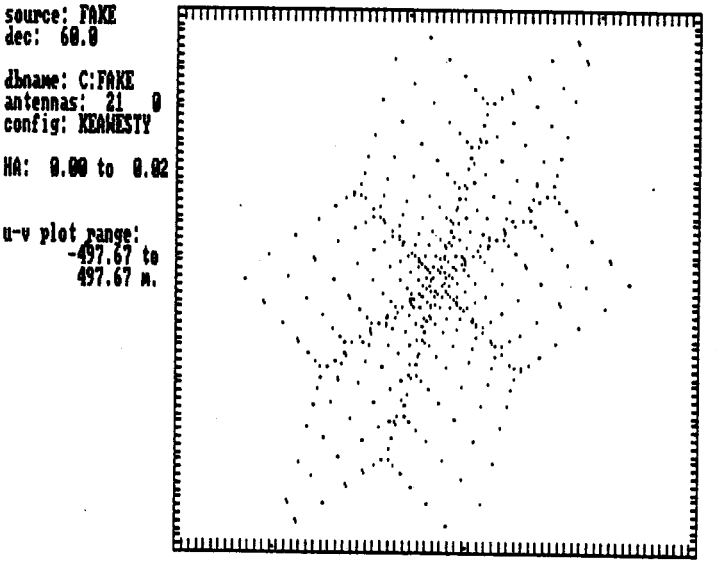
FUTURE TELESCOPE SITING AREAS TO THE YEAR 2000

MAUNA KEA SCIENCE RESERVE CDP - [redacted]

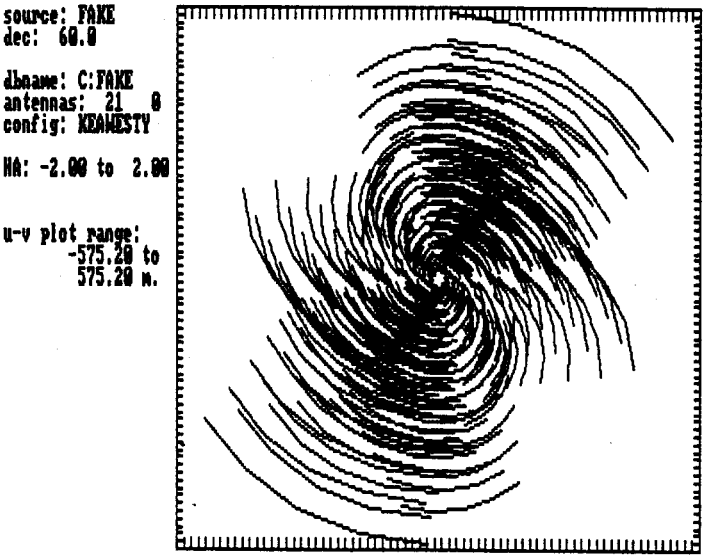
FIGURE 6



(a)
Array on Mauna Kea

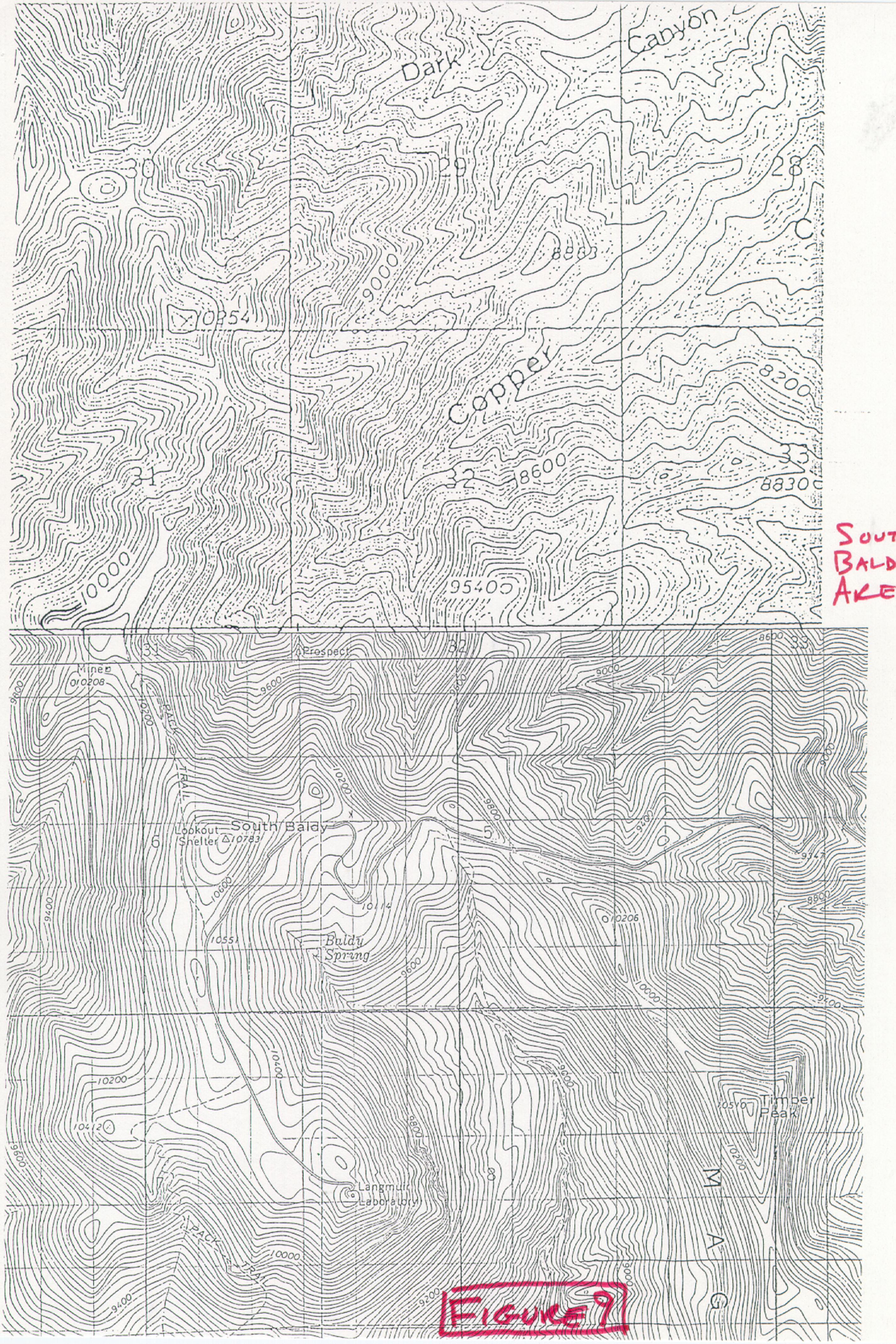


(b)
u-v Coverage for
Snapshot with
Array on Mauna Kea



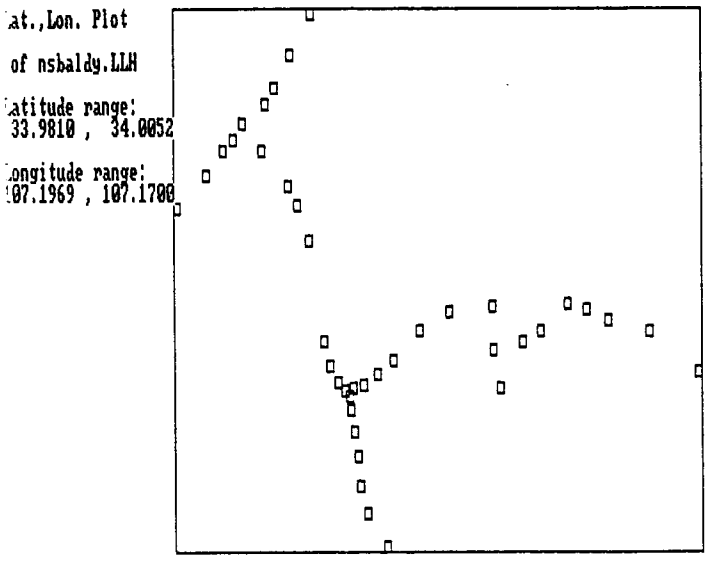
(c)
u-v Coverage for
4^h tracking with
array on Mauna Kea

Figure 8

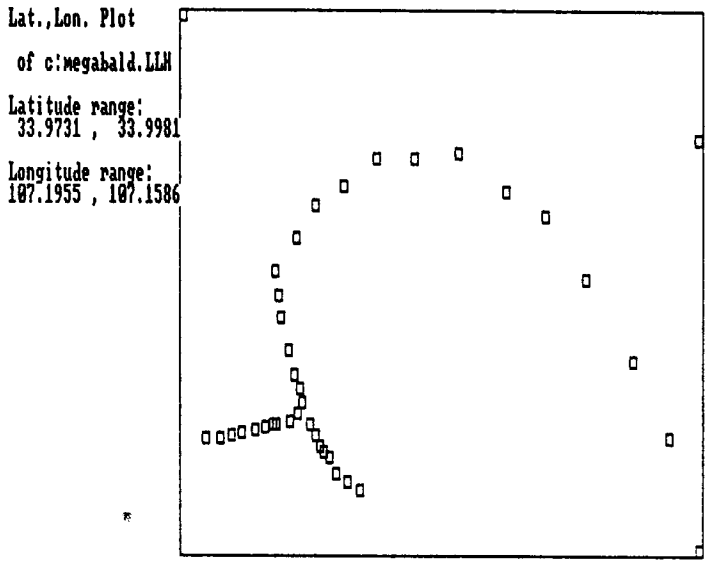


Dark
Canyon
Copper
30
29
28
31
32
33
8800
9000
8200
8600
8830
9540
10000
Prospect
Mine
10208
PACK TRAIL
Lookout Shelter
South Baldy
10783
10114
10551
Baldy Spring
10206
Langmuir Laboratory
Timber Peak
M
A
G
SOUT
BALD
ARE

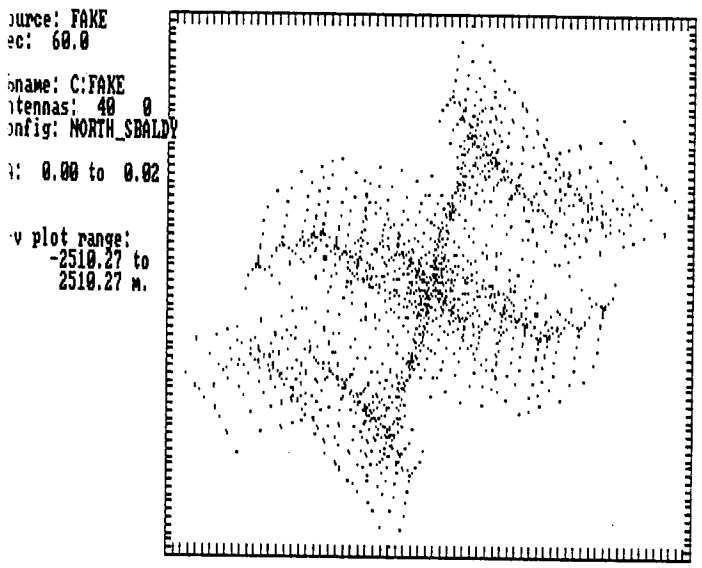
FIGURE 9



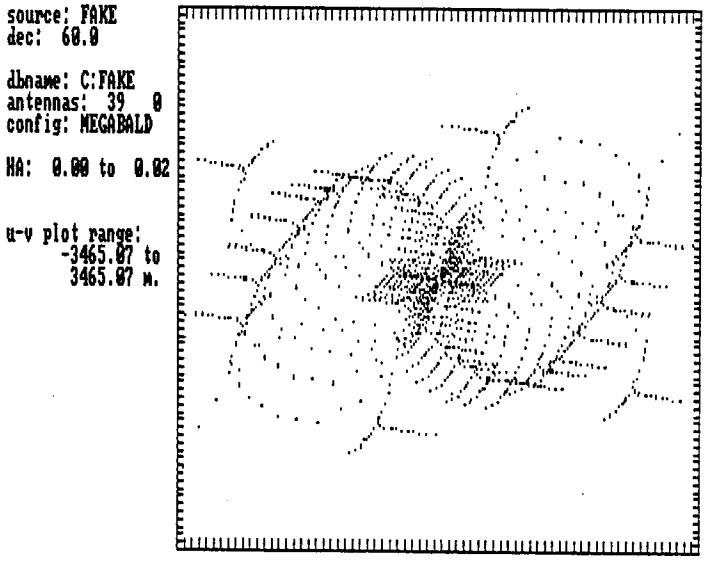
(a)



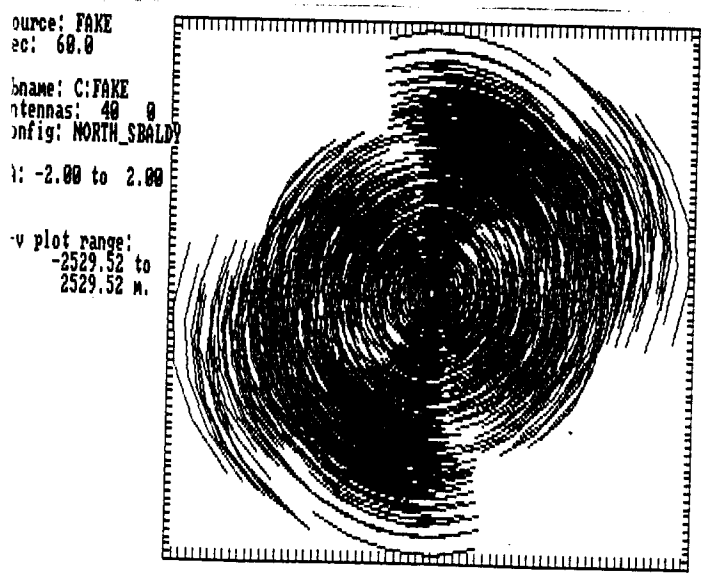
(b)



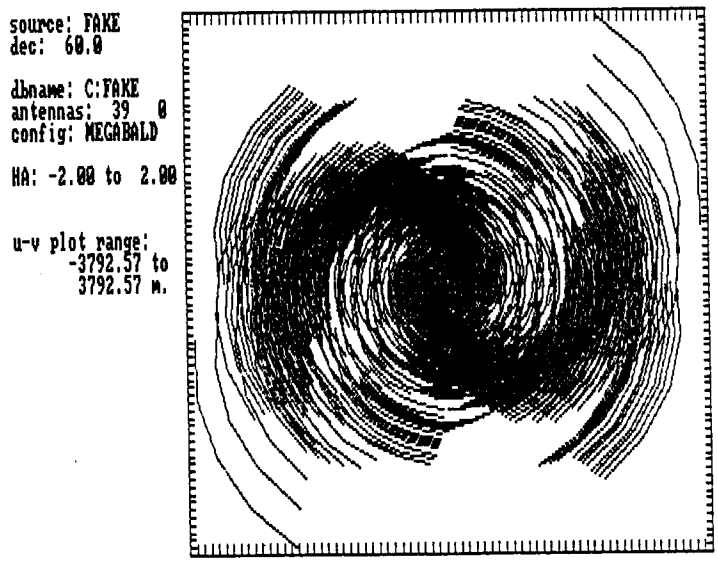
(c)



(d)



(e)



(f)

Figure 10 - Two Possible Large Configurations/Results for South Baldy Ridges

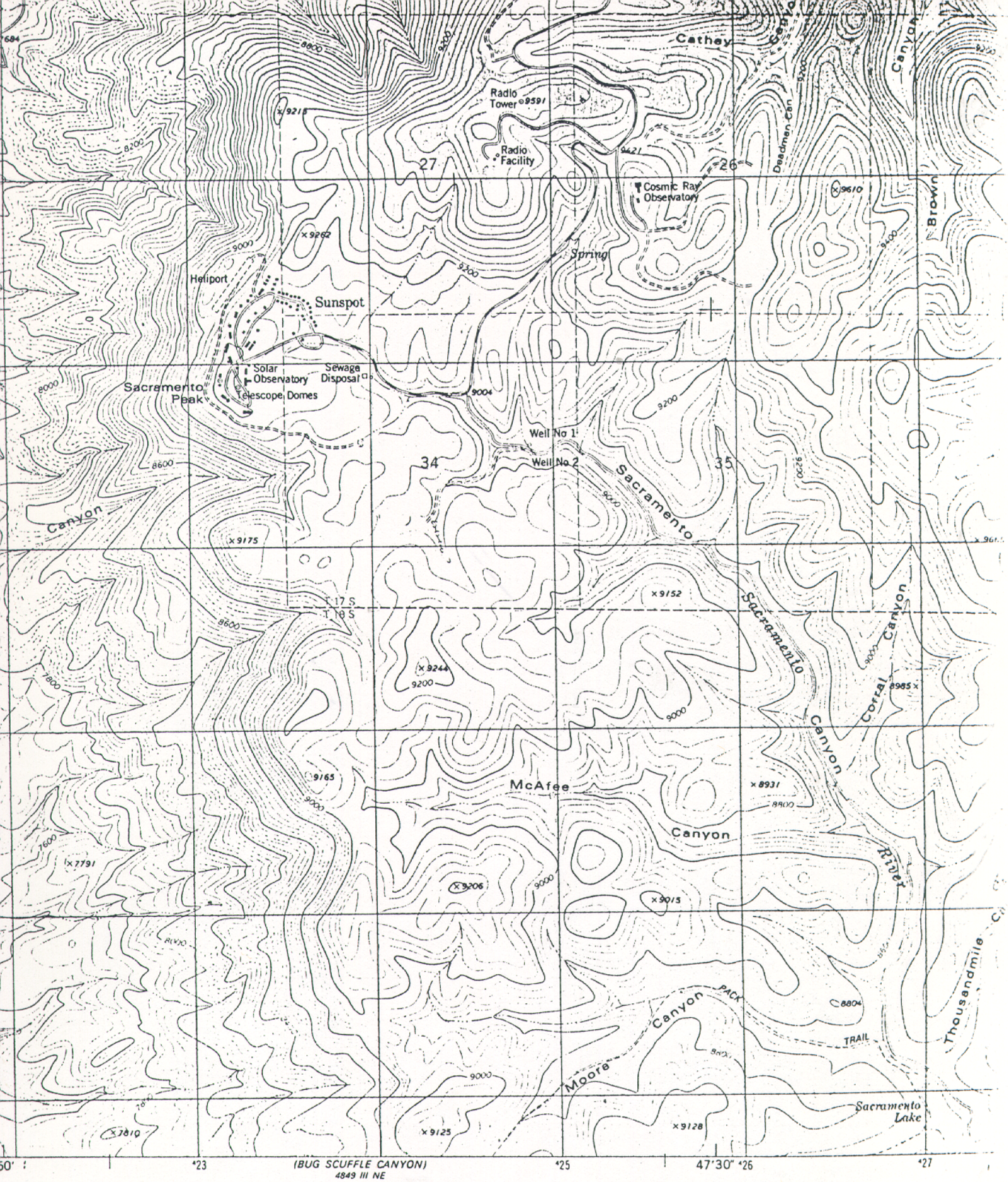
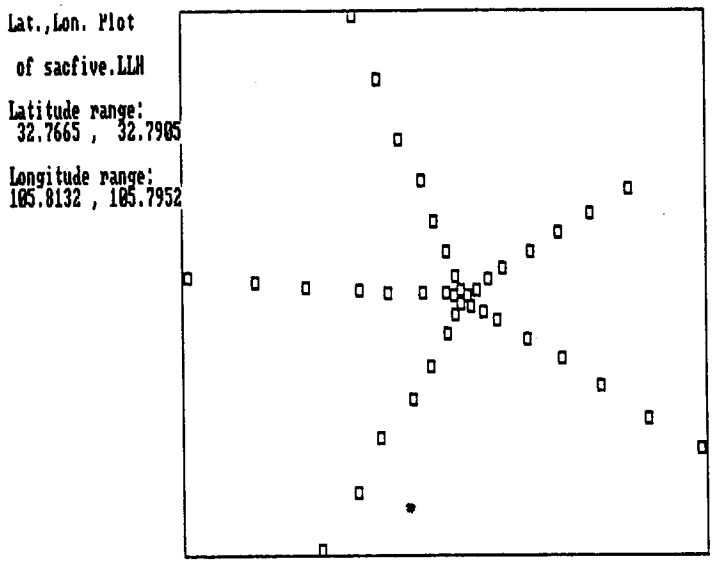
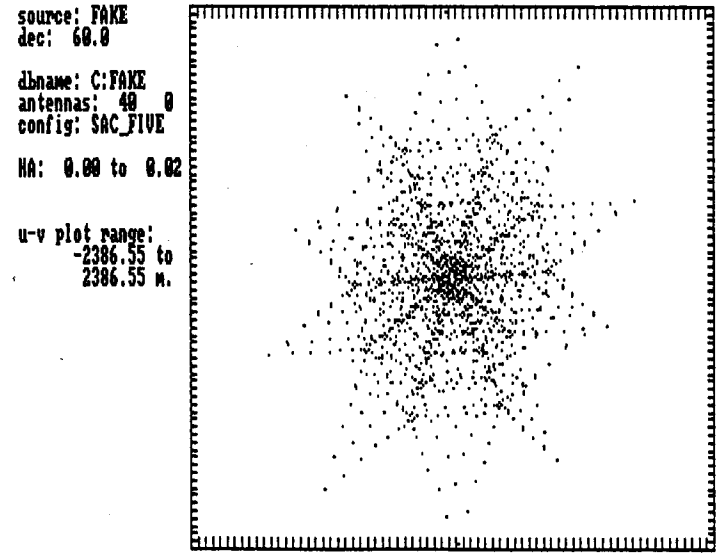


Figure 11

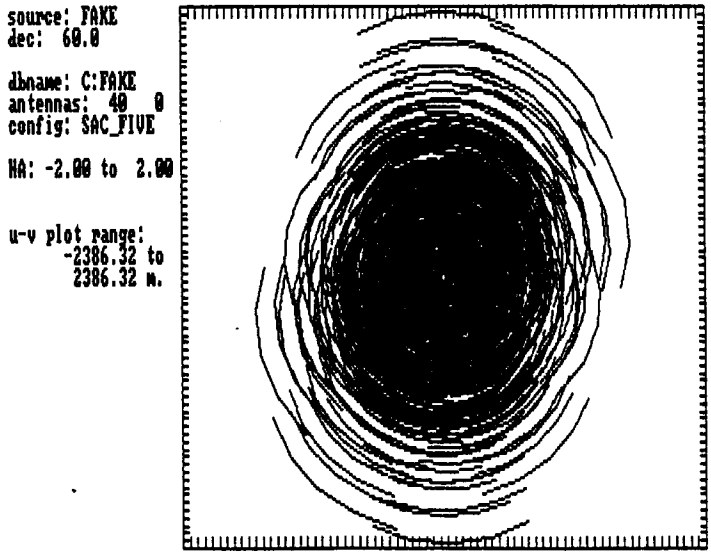
SACRAMENTO PEAK AREA



(a)
Five-armed Array Fitting Topography near Sacramento Peak, NM



(b)
u-v Plane Coverage for Snapshot with Five-Armed Array Near Sac Peak



(c)
u-v Plane Coverage for 4^{h} tracking with Five-Armed Array Near Sac Peak

Figure 12