STATE OF NEVADA
AGENCY FOR NUCLEAR PROJECTS
NUCLEAR WASTE PROJECT

NWPO-TR-017-91

QUATERNARY TECTONICS AND BASIN HISTORY OF PAHRUMP AND STEWART VALLEYS, NEVADA AND CALIFORNIA

BY

JOANNE L. HOFFARD
UNIVERSITY OF NEVADA, RENO

MAY 1991

THE NEVADA AGENCY FOR NUCLEAR PROJECTS/NUCLEAR WASTE PROJECT OFFICE (NWPO) WAS CREATED BY THE NEVADA LEGISLATURE TO OVERSEE FEDERAL HIGH-LEVEL NUCLEAR WASTE ACTIVITIES IN THE STATE. SINCE 1985, IT HAS DEALT LARGELY WITH THE U.S. DEPARTMENT OF ENERGY'S SITING OF A HIGH-LEVEL NUCLEAR WASTE REPOSITORY AT YUCCA MOUNTAIN IN SOUTHERN NEVADA. AS PART OF ITS OVERSIGHT ROLE, NWPO HAS CONTRACTED FOR STUDIES OF VARIOUS TECHNICAL QUESTIONS AT YUCCA MOUNTAIN.

THIS STUDY WAS FUNDED BY DOE GRANT NUMBER DE-FG08-85-NV10461.

University of Nevada, Reno

QUATERNARY TECTONICS AND BASIN HISTORY OF PAHRUMP AND STEWART VALLEYS, NEVADA AND CALIFORNIA

A thesis submitted in partial fulfillment

of the requirements for the degree of

Masters of Science in Geology

by

Joanne L. Hoffard

1991

UNIVERSITY OF NEVADA RENO

Center for Neotectonic Studies
Mail Stop 168
Mackay School of Mines
Reno, Nevada 89557-0135
Phone (702) 784-6067
Phone (702) 784-1382
FAX (702) 784-1766

July 17, 1991

Carl Johnson
Administrator of Technical Programs
State of Nevada
Nuclear Waste Projects Office

Dear Carl:

Enclosed is a copy of Joanne Hoffard's newly completed Master of Science thesis, entitled, "Quaternary tectonics and basin history of Pahrump and Stewart Valleys, Nevada and California," which was supported by Task 5 and the General Task of the Yucca Mountain Project of the Center for Neotectonic Studies, UNR, with funds provided by your office.

Joanne's thesis is the first detailed study of the structure and neotectonic setting of the Pahrump fault system and the basin history of Pahrump Valley, about 60 km southeast of Yucca Mountain. Her study has revealed that the Pahrump fault system is a late Quaternary right-oblique fault system some 50 km long by 30 km wide, lying east of the Furnace Creek fault in California, and trending northwestward into southern Amargosa Valley. Analysis of seismic reflection data suggests that Pahrump basin had a two-stage genesis, an early part connected with 10-15 Ma detachment faulting, and a younger part related to the dextral shear system, probably active mainly since about 4 Ma. Joanne's work makes a strong case for a regionally important late Quaternary strike-slip fault system trending toward Yucca Mountain. Further study of the structure and stratigraphy of this important area is clearly important.

This is the third recently completed thesis on neotectonics and active faulting supported by Task 5. We are grateful for the support provided by your office that made these studies possible.

With best regards,

Rich Schweickert

Richard A. Schweickert
Professor of Geology

ACKNOWLEDGEMENTS

This thesis represents the culmination of a three year study of active faults in Pahrump and Stewart Valleys supervised by Dr. David B. Slemmons and Dr. Richard A. Schweickert of the University of Nevada-Reno. This project was funded by a Department of Energy grant to the state of Nevada to study the geology in the vicinity of the proposed nuclear waste repository at Yucca Mountain, Nevada. Partial funding for fieldwork was provided by a student research grant from the Geological Society of America, Division of Structure and Tectonics. Seismic reflection profiles were generously provided at a greatly reduced price by Mr. Jim Patten, Seismic Information Services, Inc., Houston, Texas.

Special thanks to field assistants John Taylor, Greg Vick, Diane Donovan, and Mike Ellis for taking time out of their own busy schedules to lend a hand. This project has greatly benefitted from the wisdom of Jim Yount, USGS; Peizhen Zhang, Center for Neotectonic Studies, University of Nevada, Reno; Greg Vick, Weber and Associates, Santa Cruz, California; Steve Nitchman, Reno, NV; Dr. Richard A. Schweickert, Center for Neotectonic Studies, University of Nevada, Reno; and Dr. David B. Slemmons, Las Vegas, NV. Thanks also to thesis committee members Steve Wesnousky, Center for Neotectonic Studies, University of Nevada, Reno and John Bird, Department of Civil Engineering, University of Nevada, Reno for their helpful reviews of this manuscript. Thanks to Jay Quade, of Utah State University for leading me through his unpublished mapping of late Quaternary deposits in Pahrump Valley.

I especially want to thank Jo Poe and Barb Vogt, of Jo's Pizza, Pahrump, Nevada for providing a home away from home and companionship during the long weeks in Pahrump. A special thanks to Greg Vick for providing encouragement and moral support during the early phases of this study, Steve Nitchman for encouragement and numerous discussions through the writing phase, and to my family for their strength and encouragement throughout this study, and for being proud of me.

ABSTRACT

The Pahrump fault system is an active fault system located in Pahrump and Stewart Valleys, Nevada and California, in the southern part of the Basin and Range Province. This system is 50 km long by 30 km wide and is comprised of three fault zones: the right-lateral East Nopah fault zone, the right-oblique Pahrump Valley fault zone, and the normal West Spring Mountains fault zone. All three zones have geomorphic evidence for late Quaternary activity. Analysis of active fault patterns and seismic reflection lines suggests that the Pahrump basin has had a two-stage genesis, an early history associated with a period of low-angle detachment faulting probably active 10-15 Ma, and a more recent history related to the present dextral shear system, probably active post-4 Ma.

TABLE OF CONTENTS

TABLE OF CONTENTS (cont.)

TABLE OF CONTENTS (cont.)

LIST OF TABLES

LIST OF PLATES

LIST OF FIGURES

LIST OF FIGURES (CONT.)

LIST OF FIGURES (CONT.)

LIST OF FIGURES (CONT.)

INTRODUCTION

This report describes and interprets a system of active faults that is located in the southern Great Basin within Pahrump and Stewart Valleys, along the Nevada-California border (Figure 1, Plate 1). The fault system has been previously recognized on remote sensing imagery (Liggett and Childs, 1973), and various authors have mapped parts of the fault system. The purpose of this report is to map the active or Quaternary faults in detail, and to interpret the timing of the most recent activity on the faults based on the youngest stratigraphic unit or geomorphic surface cut by the faults. I analyze the fault patterns and the sense of displacement on individual faults to infer the sense of movement for the entire fault system as well as for the three fault zones within the system. I also analyze seismic reflection profiles across the faults to determine the basin geometry, the subsurface geometry of the faults and the subsurface geometry of the basin fill. This information is used to infer relative timing of events related to the basin genesis.

There is some controversy over the style of active tectonism in the region surrounding Pahrump and Stewart Valleys. Vector reconstructions of the early mountain ranges by matching Mesozoic thrust faults across low-angle

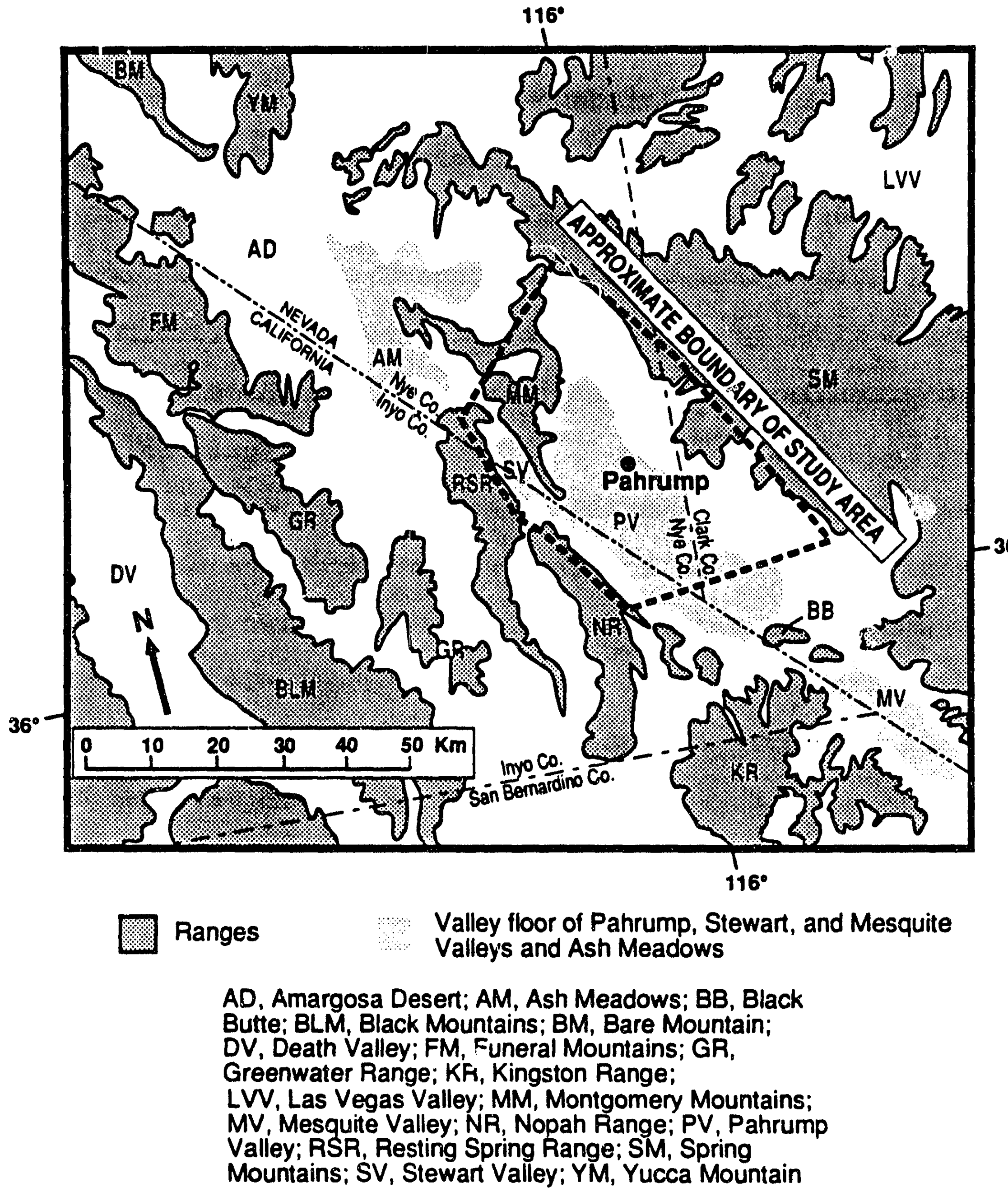


Figure 1. Location map of the study area showing some of the principal geographic features cited in text.

normal faults implies there has been as much as 500% of extension west of the Spring Mountains since 20 Ma (Wernicke et al., 1988). Other scientists have proposed that Pahrump and Stewart Valleys are pull-apart basins formed on right-lateral slip faults (Burchfiel et al., 1983; Wright, 1989). One motivation for the study of the Pahrump fault system is to determine whether the young faults are dominantly normal or strike-slip faults.

The active fault system in Pahrump and Stewart Valleys has been referred to variously as the Pahrump fault zone (Liggett and Childs, 1973), the State Line fault (Hewett, 1956; MIT Field Geophysics Course, 1985), the Pahrump Valley fault zone (Wright et al., 1981) and the Pahrump Valley fault system (Hoffard, 1990).

For convenience of presentation, I will refer to the faults as the Pahrump fault system (PFS) and divide this system into three fault zones, each with a unique character. I propose these names for the three fault zones listed here from west to east; the East Nopah fault zone (ENFZ), formerly the Nopah range front fault zone (Hoffard, 1990); the Pahrump Valley fault zone (PVFZ), formerly the Pahrump Valley-Stateline fault zone (Hoffard, 1990), and the West Spring Mountains fault zone (WSMFZ), formerly the Spring Mountains range front fault zone (Hoffard, 1990).

RELEVANCE OF THE PROJECT

The Pahrump fault system has been recognized since 1973 (Liggett and Childs, 1973), yet to date, no detailed maps or discussions of the fault system have been published. There are two motivating reasons to study the Pahrump fault system. One is to determine whether the fault system is primarily an extensional or a dextral shear system and to determine the youthfulness of the system. The other is to determine the implications of the Pahrump fault system for the regional tectonic framework.

Results from this study were aimed at deciding which of two competing hypothesis that bear on the late Cenozoic tectonic evolution of Pahrump Valley is most correct. One hypothesis predicts slow rates of ongoing extension in Pahrump Valley while the other predicts active tectonics driven by dominant dextral shear. Pahrump Valley lies at the eastern edge of the proposed zone of active extension and in the southern portion of the proposed zone of active dextral shear. Pahrump Valley lies ~70 km south of a proposed high-level nuclear waste storage facility at Yucca Mountain, Nevada. Several north-south trending late Quaternary faults have been identified at Yucca Mountain and though a right-lateral component is suggested for these faults, the driving mechanism for the fault activity is poorly understood. A possible mechanism is a proposed major

major crustal dextral shear zone that may extend from south of Pahrump Valley into the Yucca Mountain area (Schweickert, 1989).

The Black Mountains bordering eastern Death Valley (Figure 1) is generally considered to be the eastern limit of major Quaternary activity within the highly extended zone (Wright et al.,1983; Wernicke et al., 1988). However, Pahrump Valley lies east of the Black Mountains. Thus, demonstration of Quaternary activity on the fault system in Pahrump Valley extends the zone of Quaternary activity farther to the east than presently recognized.

The analysis of the patterns, timing and subsurface geometry of the active faults of the Pahrump fault system may help to determine whether the present fault activity in Pahrump is primarily normal or strike-slip, if the modern tectonic regime for the region is driven dominantly by extension or dextral shear, whether there is youthful activity within the PFS, and the approximate orientation of the local strain field.

In this report I will provide a brief overview of the patterns of faults within Pahrump and Stewart valleys and discuss constraints on timing and slip direction for each fault zone. I then present data from seismic reflection profiles and discuss the implications of the basin geometry and subsurface fault geometry to infer a sequence of events in the evolution of Pahrump and Stewart Valleys. Last, I discuss the regional implications of this study, and suggest some possible topics for future research.

PURPOSE OF THE STUDY

The primary purpose of this thesis was to present mapping and description of Quaternary and late Tertiary faults in Pahrump Valley and Stewart Valley within the southern Basin and Range; and to determine age, style, and dimension of the Pahrump fault system. To accomplish this, the following tasks were undertaken:

1. Map the faults on aerial photographs and field check major faults to produce an annotated compilation of Quaternary and late Tertiary faults.

2. Ascertain the type of movement on the faults, (i.e. normal, strike-slip, reverse), based on offset geomorphic features, scarp facing direction, fault exposures, and slickensides.

3. Constrain the ages of fault events based on geomorphic expression of the faults and associated geomorphic surfaces including qualitative analysis of scarp morphology and exploration for datable deposits.

4. Ascertain the style of recent movement for the fault zone as a whole based on fault patterns and inferred movements on individual faults.

5. Conduct a review of literature and map data to gain information about long-term movement on the fault system and its tectonic setting.

6. Analyze seismic reflection lines to gain information about the subsurface geometry of the fault zone, the basin geometry, and folding or tilting of reflectors; to gain information about the style of faulting.

7. Analyze local strain based on fault patterns and styles.

8. Make recommendations for future studies in Pahrump and Stewart Valleys.

Only certain of these original tasks were completed. The Pahrump fault system was mapped and subdivided into three distinct fault zones based on unique tectonic styles within each zone. Late Quaternary fault activity has been recognized for each of the three fault zones, thus qualifying them as potentially active faults (Slemmons, 1977). The seismic lines are interpreted, and subsurface fault geometries are related to features observed at the surface.

Inferences about ages of the faults are speculative: they are based on existing maps of geomorphic surfaces, rough correlation to mapped deposits in neighboring valleys, and unpublished stratigraphic mapping of Holocene and upper Wisconsin deposits in Pahrump Valley. Due to lack of funding and land access restrictions, no trenches were excavated across the Pahrump Valley faults.

INTRODUCTION TO THE STUDY AREA

The area mapped for this study includes most of the region of active faults within the PFS (Figure 2). This region is bordered on the east by the Spring Mountains, on the northeast by the northern termination of Pahrump Valley at the Montgomery Mountains, on the northwest at low-lying

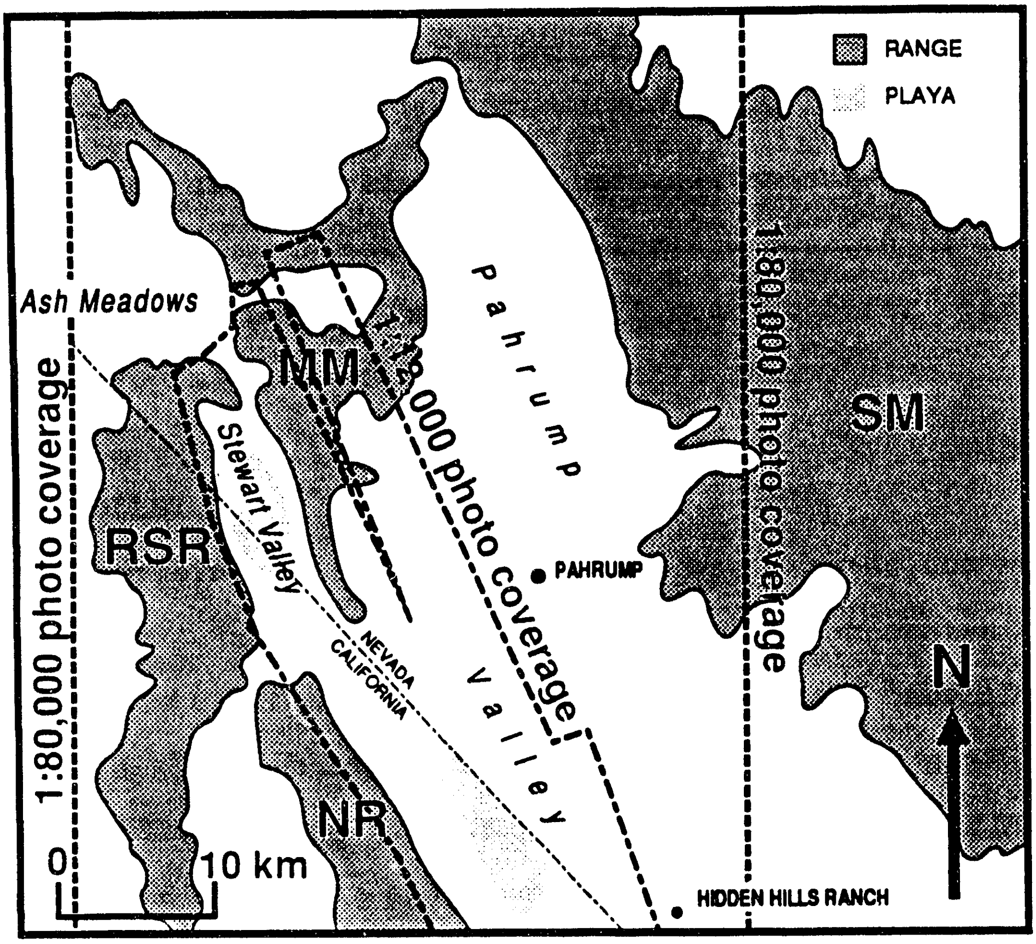


Figure 2. Boundaries of areas covered by 1:12,000 scale low-sun-angle; and 1:80,000 scale, black and white, U-2 flown aerial photography. Abbreviations as shown on Figure 1.

hills separating Stewart Valley from Ash Meadows, and on the west by the east flanks of the Resting Spring and Nopah ranges (Figure 2). The southern boundary of the study area was drawn somewhat arbitrarily, just south of latitude 36° North near Hidden Hills Ranch, because low-sun-angle air photo coverage was not available for areas south of the Hidden Hills ranch. The active PFS continues for approximately 20 km south of the Hidden Hills ranch.

METHODOLOGY

The main products of this study are a 1:100,000 scale fault map (Plate 1 in back pocket) and four annotated 1:24,000 scale fault maps on an orthophotoquad base (Plates 2, 3, 4, and 5 in back pocket; Figure 3). Mapping was accomplished by analysis of 25 1:80,000 scale, black and white, U-2 flown air photos covering approximately 2,225 km^2; and 323 black and white, low-sun-angle air photos covering approximately 850 km^2 (Figure 2). Over 250 km of faults were mapped and selectively field checked. Faults were transferred onto a 1:100,000 scale topographic base and onto orthophoto bases with a Map-o-graph projection instrument. To reduce distortion, the projection was scaled to a small area surrounding each fault, and features common to both the base map and the photo, such as streams, roads and vegetated areas, were aligned.

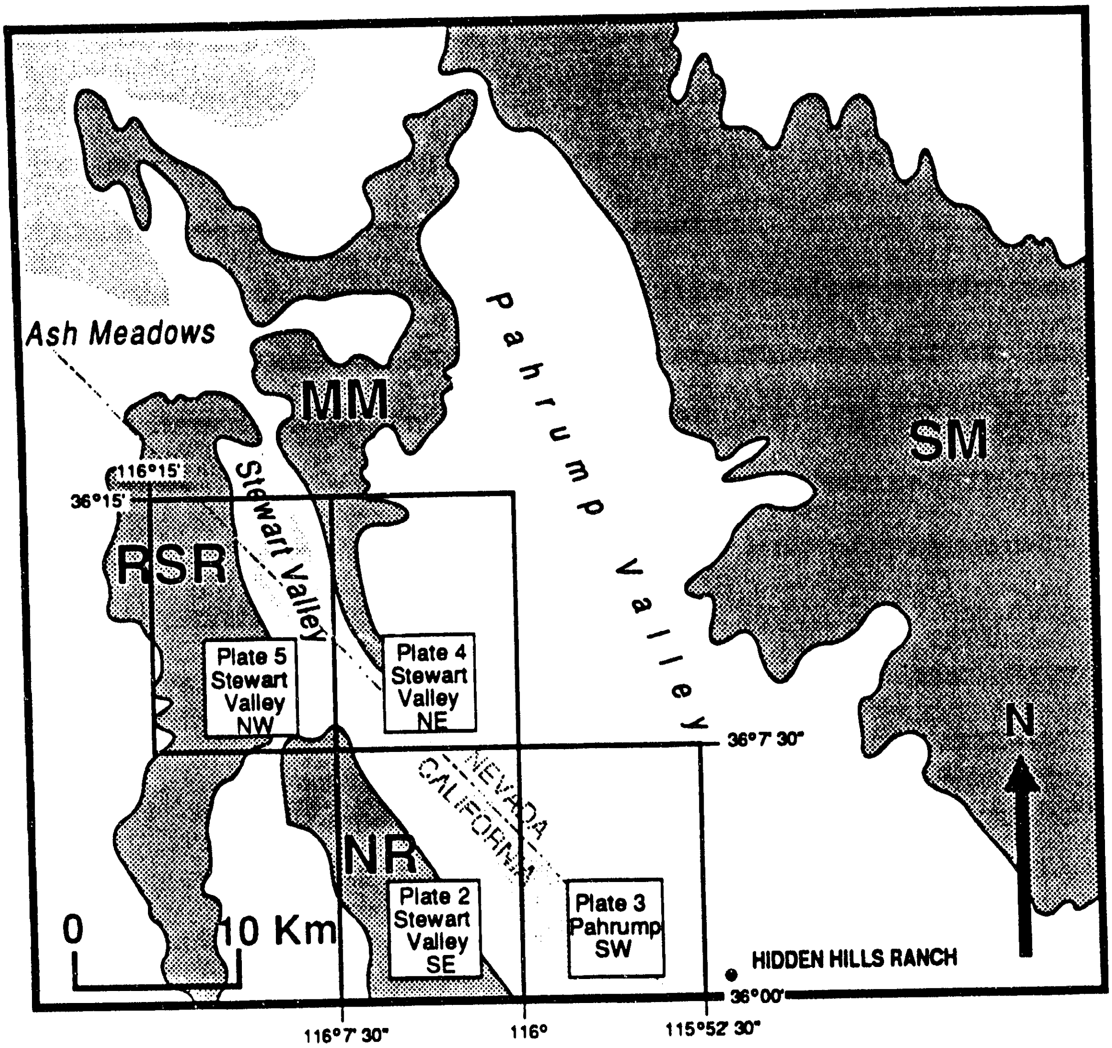


Figure 3. Location map for the annotated fault maps shown on Plates 2, 3, 4, and 5.

PHYSIOGRAPHY

Pahrump Valley and Stewart Valley, Nevada and California lie just west of Las Vegas Valley (Figure 1). These valleys are bordered by the Spring Mountains on the east, the Montgomery Mountains (shown on Plate 1 as the Last Chance Range) on the north, the Resting Spring Range and the Nopah Range on the west, and Mesquite Valley on the southeast. The town of Pahrump and the northern part of Pahrump Valley are located in Nye County, Nevada; the western parts of Pahrump Valley and Stewart Valley are located in Inyo County, California; and the southeast end of Pahrump Valley is located in Clark County, Nevada (Figure 1). Pahrump Valley can be reached by turning south off of U.S. Highway 95, ~100 km northwest of Las Vegas onto Nevada Highway 160. The town of Pahrump is 45 km south of the junction. Pahrump Valley can also be reached by turning west off of U.S. Interstate 15, ~16 km south of Las Vegas, onto Nevada Highway 160, or by traveling east on California Highway 178 (Nevada Highway 372) from Shoshone.

POPULATION/CLIMATE

The population of Pahrump Valley is about 10,000, with most of the population located in the town of Pahrump. Mean annual rainfall averages 11.9 cm and mean annual snowfall averages 3.3 cm. Summer temperatures range from 14° to

35° C and winter temperatures range from -1° to 51° C (Pahrump visitor center handout). The dominant vegetation in Pahrump and Stewart Valleys is creosote, sage, mesquite, yucca, desert grasses, pear cactus, barrel cactus, and cholla cactus.

GEOMORPHOLOGY

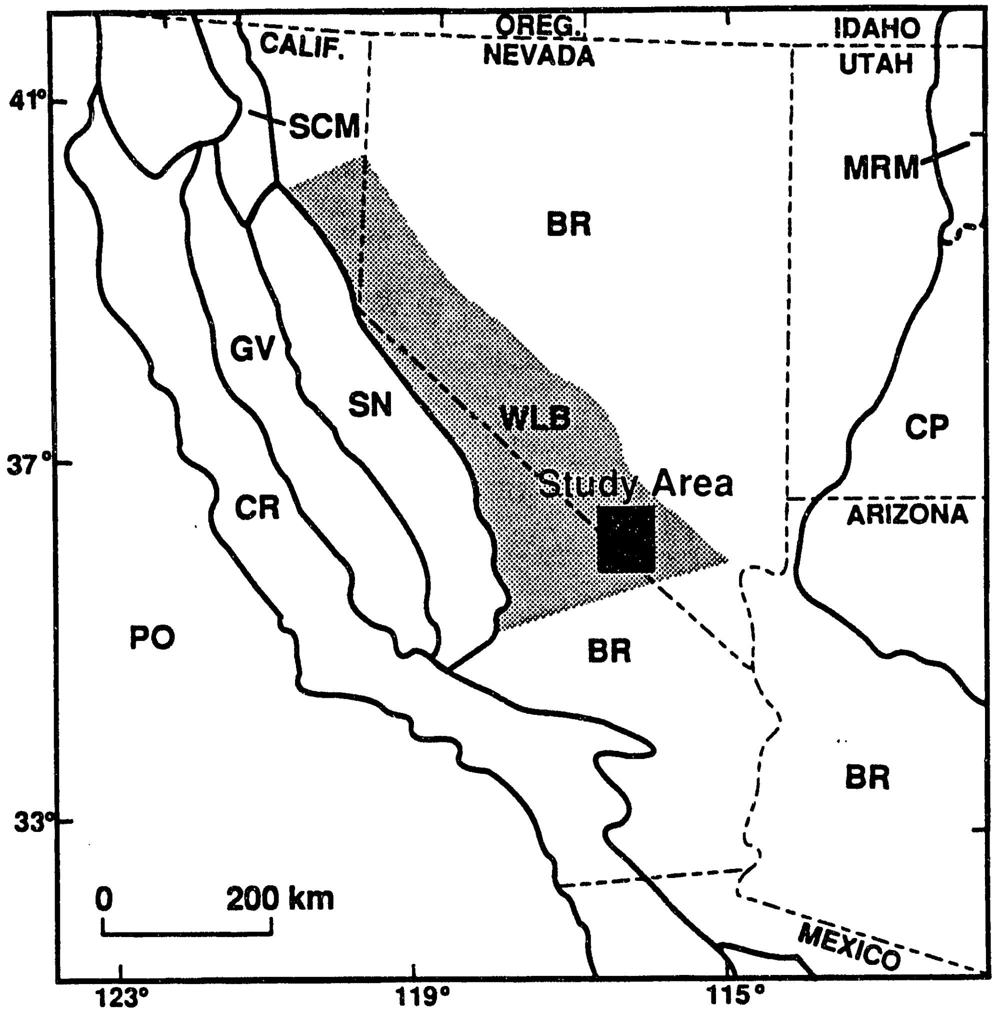
Pahrump and Stewart Valleys are low-relief valleys lying between the Spring Mountains (maximum elevation 3,632 m) on the east and the lower elevation Nopah and Resting Spring ranges (maximum elevations 1,751 m and 1,605 m respectively) on the west. Elevation of the valley floor averages 820 m above sea level. Minor relief within the valley floor is related to valley floor faults and does not exceed 50 m. Pahrump and Stewart Valleys are alluvium filled bolsons (as defined by Peterson, 1981), each having an internal drainage system. In the eastern portion of Pahrump Valley, the piedmont slope of the Spring Mountains range front is dominated by two large alluvial fans that coalesce with several smaller alluvial fans. These fans are dissected; the mountain-valley fans consist of a partial ballena and fan remnants, and the inset fans of the lower piedmont represent a zone of coalescing fan aprons. This apron is built onto an alluvial flat in northern Pahrump Valley, and partially buries a pediment surface in southern

Pahrump Valley. In the western part of Pahrump Valley, the piedmont slope of the Nopah Range is dominated by medium-sized fans that consist of erosional fan remnants near the range front that are buried by a coalescing fan apron along the lower piedmont. The lower piedmont forms a sharp, linear boundary with the bolson floor playa.

In Stewart Valley, the piedmonts of the Resting Spring Range on the west and the Montgomery Mountains on the east consist of small, coalescing alluvial fans that have a sharp boundary with a playa in the bolson floor. The playa of Stewart Valley is separated from the playa in Pahrump Valley by a low drainage divide, less than 30 m in elevation. The two playas are located along the west side of the bolson floor, and all drainages of Pahrump Valley and Stewart Valley debouch into these playas. Drainages from the Spring Mountains dissect the pediment in southern Pahrump Valley and the alluvial flat in northern Pahrump Valley before reaching the playa.

REGIONAL TECTONIC SETTING

Pahrump Valley lies within the southern Great Basin, near the southern end of the Walker Lane belt, a 700 km long, northwest-trending zone of strike-slip faulting and diverse topography recently described by Stewart (1988; Figure 4). It also lies near the eastern edge of the Death



BR, Basin and Range Province; CP, Colorado Plateau; CR, Coast Ranges; GV, Great Valley of California; KM, Klamath Mountains; MRM, Middle Rocky Mountains; PO, Pacific Ocean; SCM, Southern Cascade Mountains; SN, Sierra Nevada; WLB, Walker Lane Belt.

Figure 4. Location of the Walker Lane Belt. (After Stewart, 1988).

Valley normal fault system (DVNFS), a zone of major late Cenozoic extension between the Sierra Nevada on the west and the Spring Mountains on the east (Wernicke et al., 1988; Figure 5). The PFS also lies near the southern end of a major dextral shear zone proposed by Schweickert (1989; Figure 6).

THE WALKER LANE BELT

The Walker Lane belt (WLB) was described by Stewart (1988), as a zone of primarily strike-slip faulting, 700 km long and 100-300 km wide, that lies along the western edge of the Great Basin. This zone includes an area of diverse topography that is distinct from north-northeast trending basin-range topography on the east. Characteristic structures of the WLB are northeast-trending sinistral and northwest-trending dextral strike-slip faults, unique regional structural blocks, basin-range blocks, oroflexural folds, and areas of large-scale extension including detachment faults and metamorphic core complexes (Stewart, 1988). Stewart (1988) suggested the WLB was initiated in the Mesozoic as a zone of right-lateral faulting along and in back of a magmatic arc related to oblique subduction of the Farallon plate beneath the North American plate margin.

Stewart (1988) divided the Walker Lane belt into nine blocks based on unique structural characteristics within

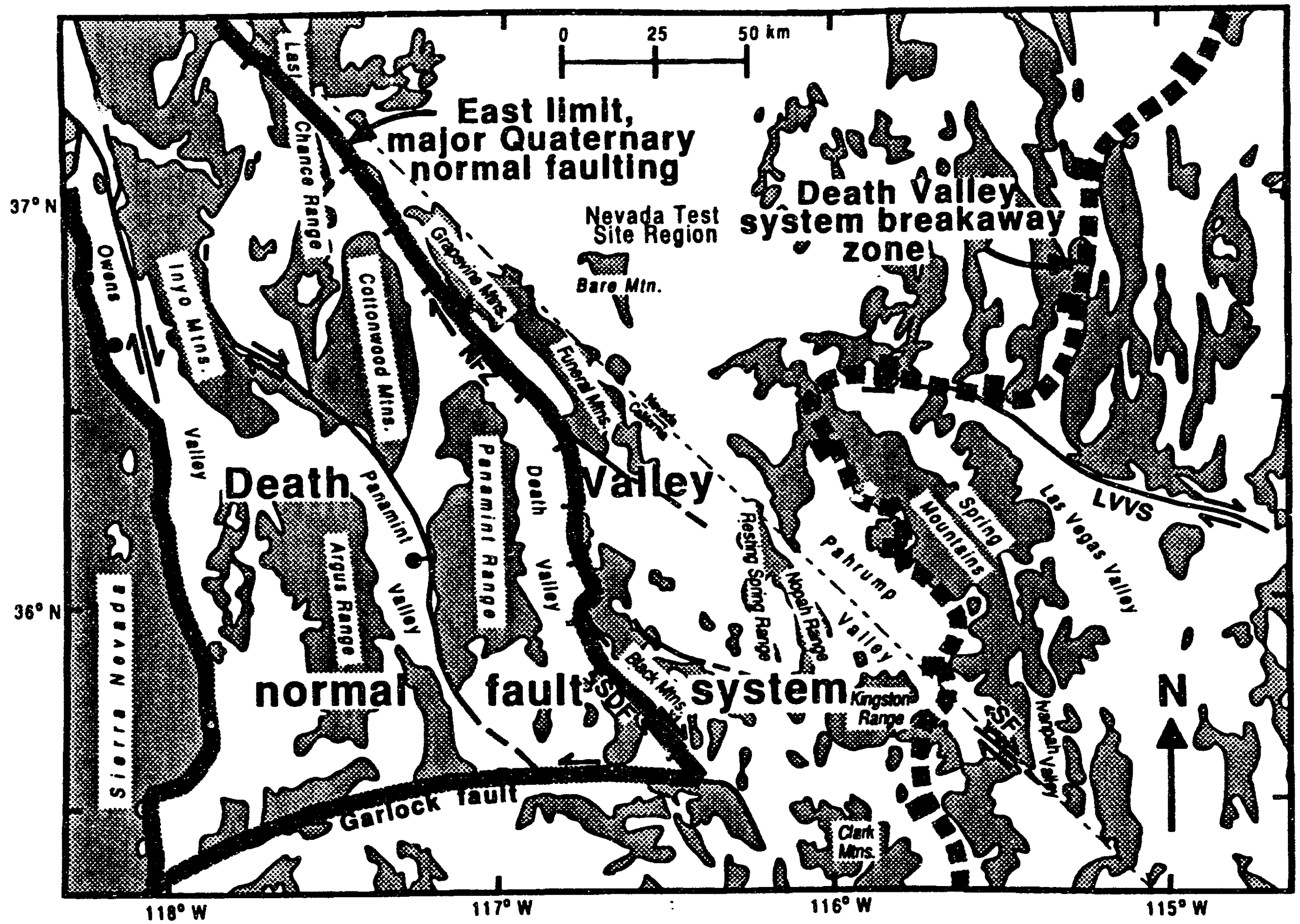


Figure 5. Location map of the Death Valley normal fault system. The figure shows the major Quaternary faults within the Death Valley normal fault system, the location of the proposed breakaway zone for the system, and the zone of major Quaternary extension. (Modified from Wernicke et al., 1988). LVVS, Las Vegas Valley shear zone; NFZ, northern Death Valley - Furnace Creek fault zone; SDF, southern Death Valley fault zone; SF, State Line fault.

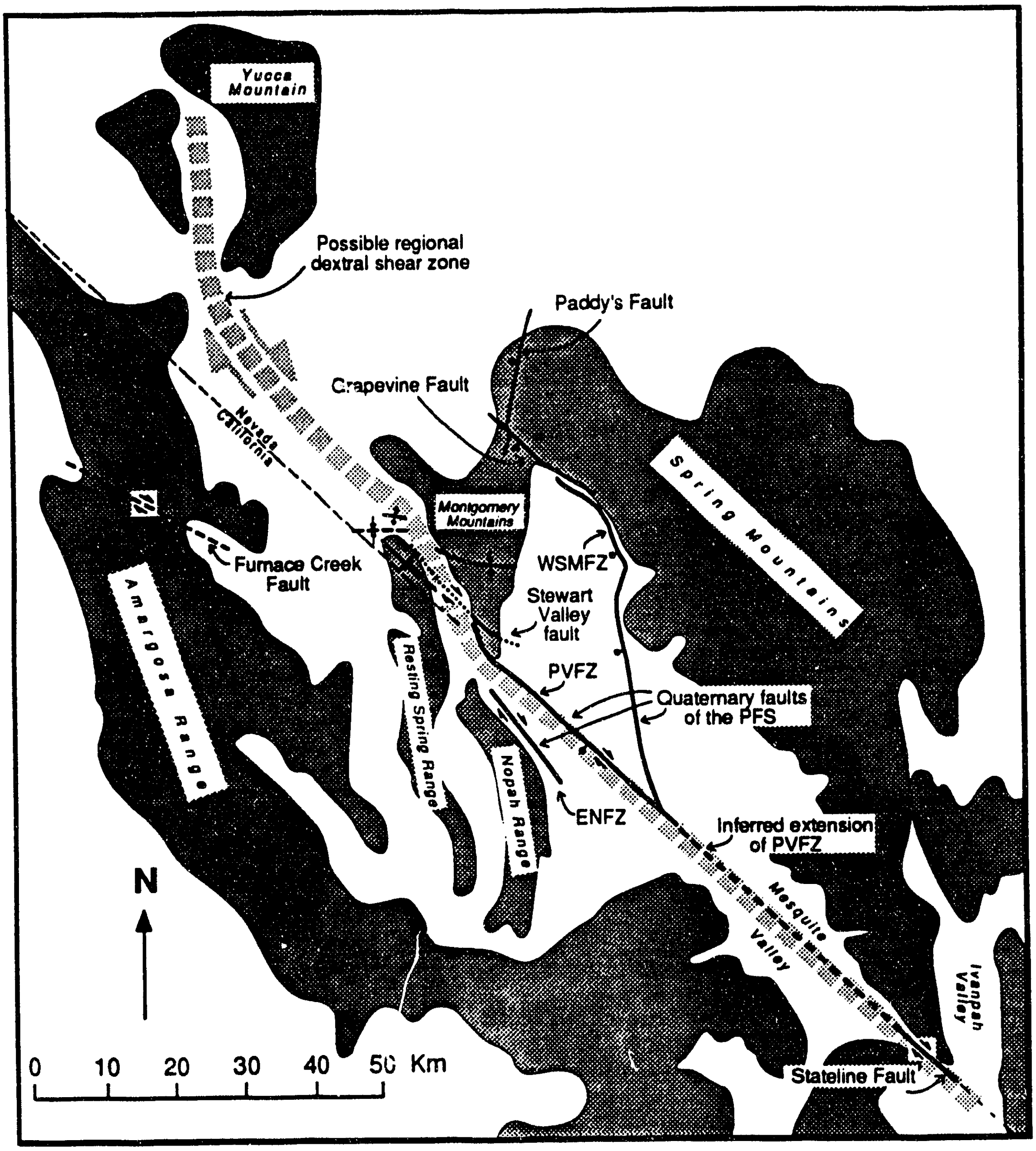


Figure 6. Structure map showing important faults and folds in the vicinity of Pahrump and Stewart Valleys. These include the State Line Fault of Hewett (1956), the Grapevine fault, Paddy's fault and the Stewart Valley fault and related folds of Burchfiel et al. (1983), the State Line - Crater Flat shear zone postulated by Schweickert (1989), and the East Nopah fault zone (ENFZ), Pahrump Valley fault zone (PVFZ), and West Spring Mountains fault zone (WSMFZ) of this study.

each block. These blocks act independently of one another. He placed the PFS within the Inyo-Mono section following Carr (1984). The Inyo-Mono section is bordered by the Sierra Nevada block on the west, the Coaldale-Excelsior section on the north, the Furnace Creek fault on the northwest, the Pahrump fault zone (PVFZ of this report) on the east and the Garlock fault on the south (Figures 5 and 7). The Inyo-Mono section is characterized by high relief, abrupt linear mountain fronts, and major northwest trending right-lateral faults.

Stewart (1988) proposed that deformation in the Walker Lane belt ranges from dominantly strike-slip to dominantly extension and results from repeated changes in the stress field from a northerly maximum compressive stress (strike-slip) to a vertical maximum compressive stress (extension).

DEATH VALLEY NORMAL FAULT SYSTEM

Wernicke et al. (1988) described the Death Valley normal fault system (DVNFS) as one of two highly extended zones lying at the latitude of Las Vegas, Nevada. These two extended zones are separated by a relatively unextended zone centered on the Spring Mountains. The boundaries of the DVNFS are coincident with the Inyo-Mono section of the Walker Lane Belt (Stewart, 1988). Thus both authors recog-

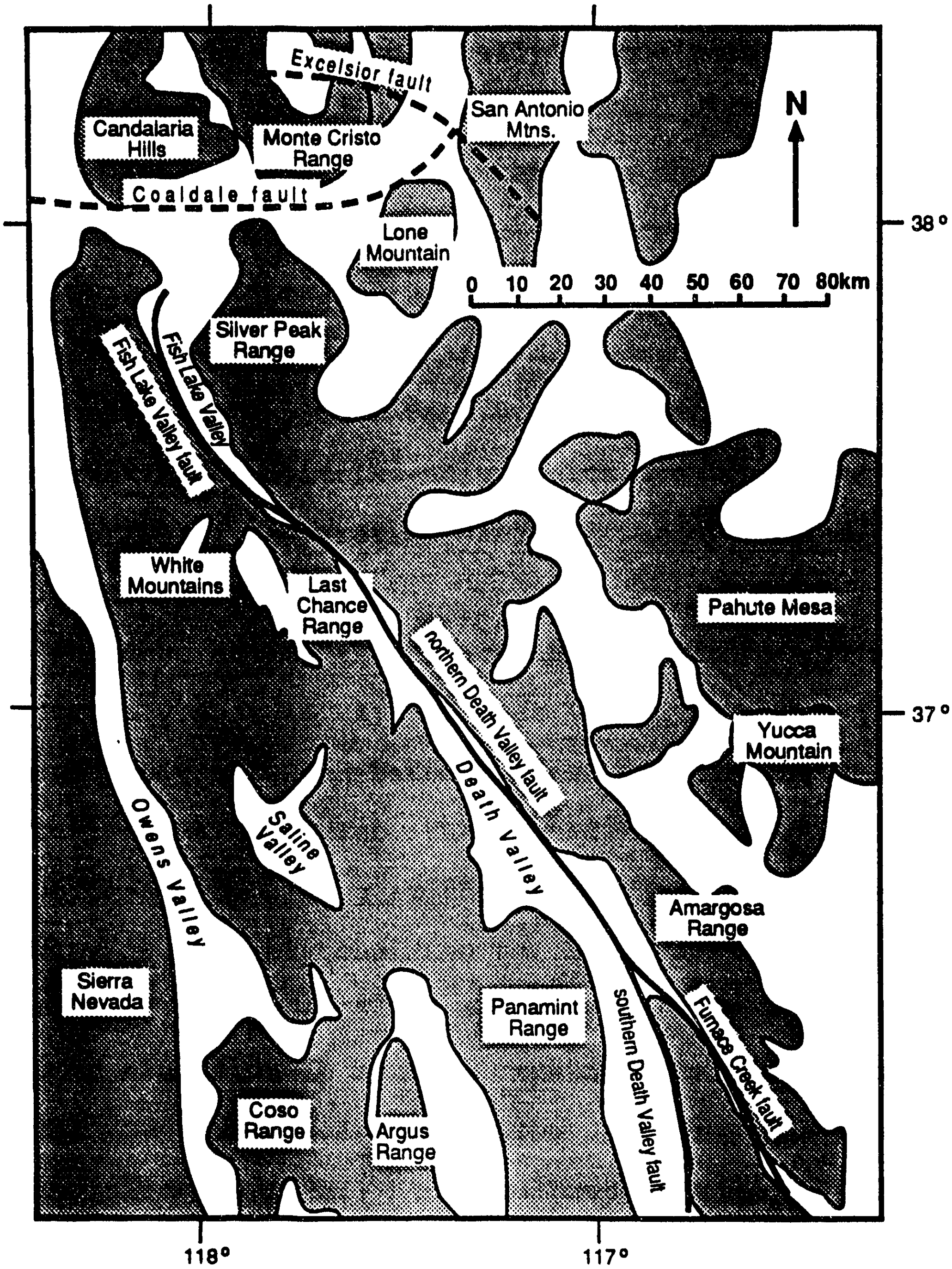


Figure 7. Location map of the Death Valley-Fish Lake Valley region.

nized this region as structurally unique relative to surrounding areas.

The DVNFS covers an area that has undergone large-scale extension characterized by east-tilted ranges translated westward from a 'breakaway zone' at the Spring Mountains, along one or more major crustal detachments (Wernicke et al., 1988). Extensional faults are considered to be the master faults, and strike-slip faults are viewed as accommodation faults, separating areas of variable rates or magnitude of extension.

Wernicke et al. (1988) argued the bulk of the extension was probably post 15 Ma, and that in the DVNFS, major extension probably occurred between 15-10 Ma, slowing during the period 10-5 Ma. However, they noted that low rates of extension are occurring at the present time and that most activity is probably confined to the area west of the Black Mountains. Wright (1984) suggested that there has been a westward migration in maximum crustal extension, and that much of the tilting of the Resting Springs Range was accomplished prior to 9 Ma. He noted that extension from 4 Ma to the present has occurred mainly west of the Black Mountains.

THE STATE LINE - CRATER FLAT SHEAR ZONE

Schweickert (1989) proposed that a dextral shear zone extends from Ivanpah Valley along the PFS, north through the southern Amargosa Desert and into Crater Flat along the west side of Yucca Mountain (Figure 6). He informally referred to this shear zone as the State Line - Crater Flat shear zone (R. Schweickert, pers. comm.).

Schweickert (1989) suggested that there has possibly been 20-25 km right-lateral slip across the shear zone since 11 Ma, that the shear zone was probably active during times of basaltic volcanism 3.2 Ma, 1.2 Ma and less than 30 Ka, and that this shear zone is probably intermittently active at the present time.

PREVIOUS STUDIES

Previous work on some faults within the PFS and related faults of the surrounding region is summarized below.

Hewett (1956) mapped the northwest-trending State Line and Ivanpah faults, and the north-trending McCullough fault and noted that the State Line fault has 2,000 feet (610 m) of dip-slip displacement from the latest (period of) movement on the fault.

Malmberg (1967) mapped the surficial geology of Pahrump Valley as part of a hydrologic investigation for the state of Nevada (Figure 8) and assigned a Plio-Pleistocene(?) age to the uplifted lacustrine beds along the PVFZ. Figure 9 shows a modified version of Malmberg's interpretation of Pahrump Valley stratigraphy.

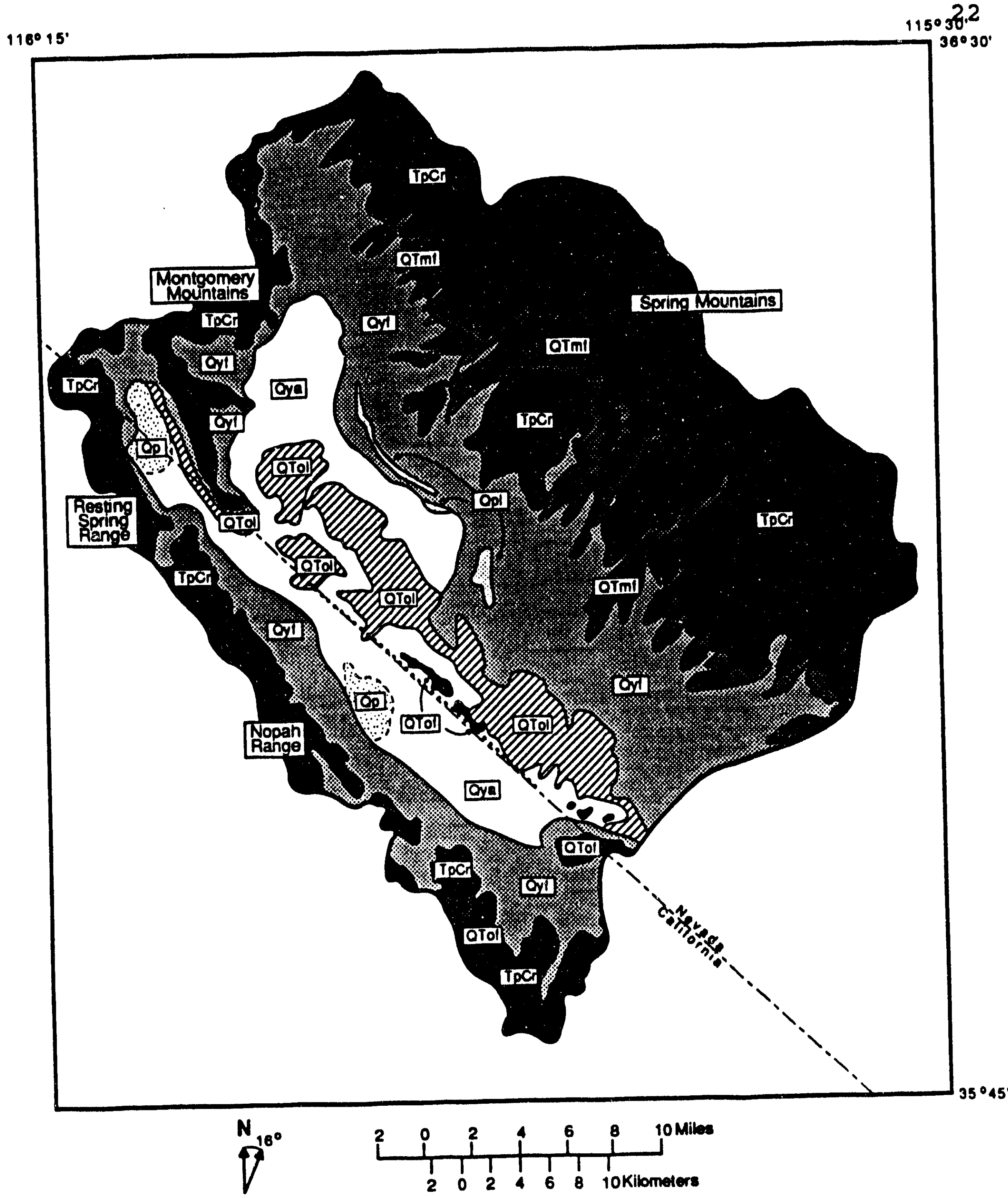


Figure 8. Generalized geologic map of Pahrump and Stewart Valleys. See figure 9 for explanation. (Modified from Malmberg, 1967).

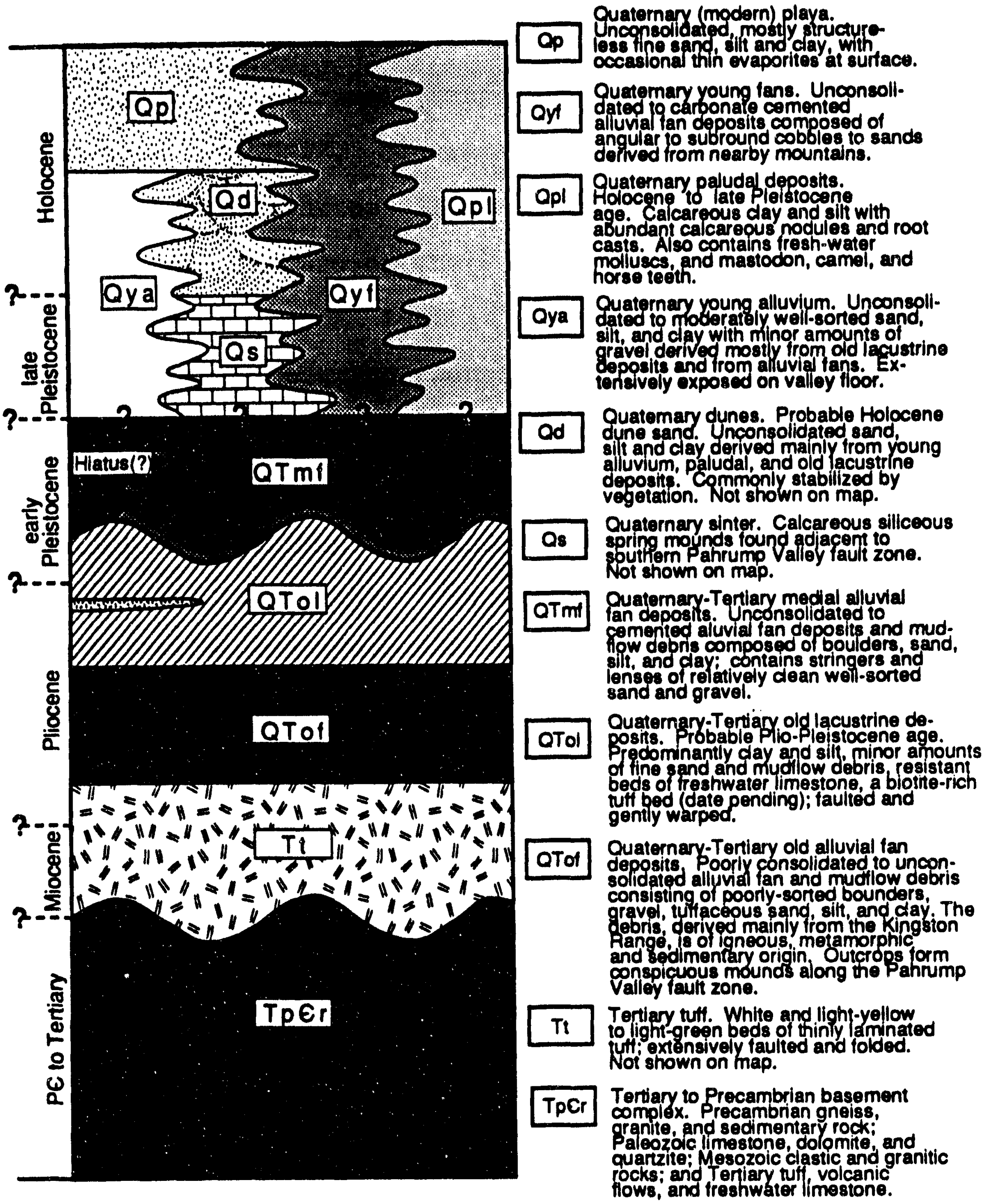


Figure 9. Pahrump Valley stratigraphy. (Modified from Malmberg, 1967).

Malmberg showed several mapped traces of the PFS, including the westernmost trace of the PVFZ and a small portion of the WSMFZ. Figure 10 is a diagrammatic cross section through Pahrump Valley (after Malmberg, 1967) showing the western trace of the PVFZ to be a west-side-down, graben-bounding normal fault. He estimated the vertical displacement to be 1,600 feet (488 m), west-side-down, based on displacement of lithologic units in the basin deposits.

Liggett and Childs (1973) suggested the name Pahrump fault zone for a major fault zone along the California-Nevada state line. They recognized several of the major traces of the PVFZ and were the first to suggest a right-lateral component of displacement along the fault based on left-stepping, en echelon traces of the fault, and a possible right-lateral stream offset. They also noted that bouguer gravity anomalies coincide with the PVFZ.

Burchfiel et al. (1983) mapped several east-vergent Mesozoic thrusts in the Montgomery Mountains and the northern halves of the Nopah and Resting Spring ranges. They also recognized several high-angle Cenozoic faults including the right-lateral Stewart Valley fault and the dip-slip Grapevine fault (Figure 6). Burchfiel et al. (1983) suggested that the Pahrump fault of Liggett and Childs (1973) may be genetically related to, but younger than, the Stewart Valley fault.

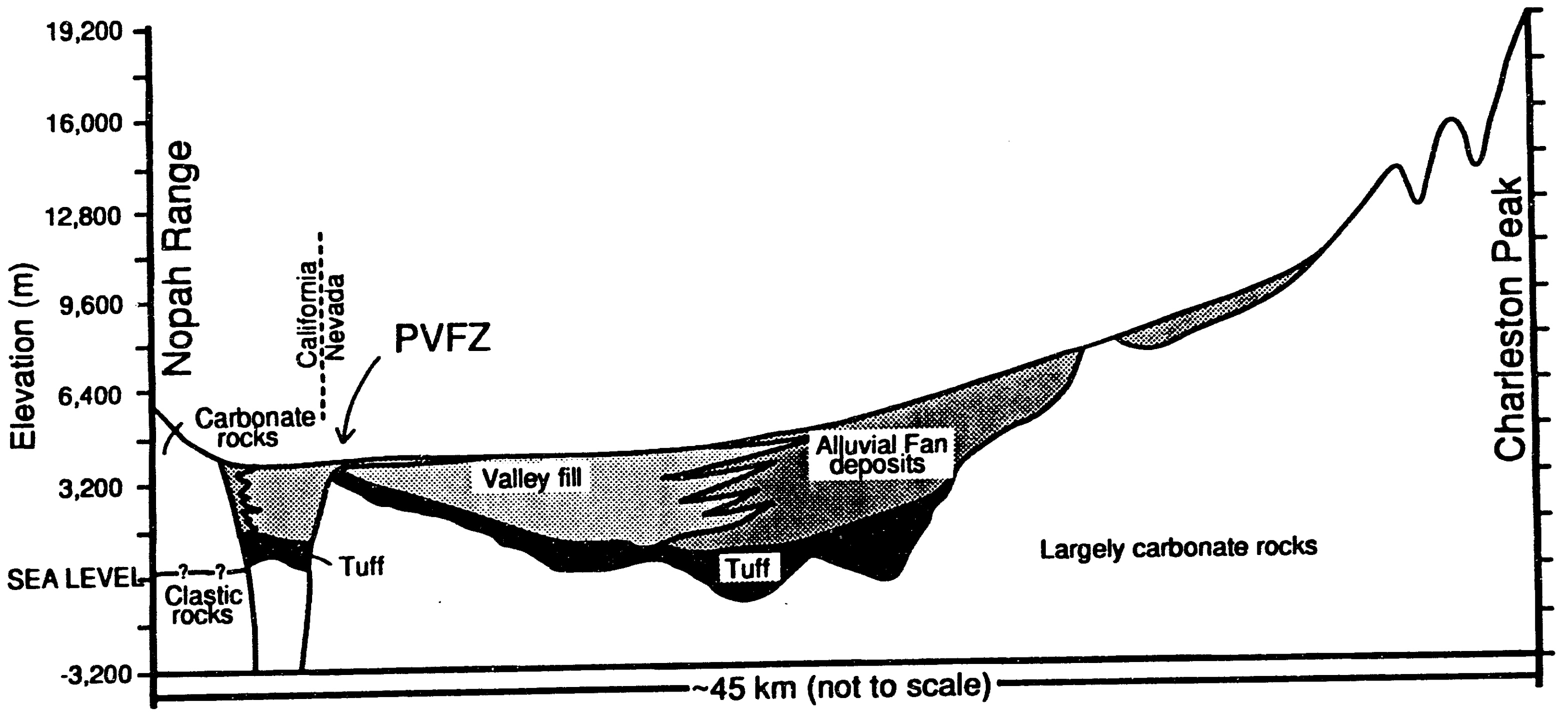


Figure 10. Diagrammatic east-west cross section through central Pahrump Valley. (After Malmberg, 1967).

According to the Massachusetts Institute of Technology (MIT Field Geophysics Course, 1985), bouguer gravity anomalies and telluric currents suggest that Black Butte, located south of Pahrump Valley (Figure 1), is an allochthonous mass, separated from the basement by hundreds of meters of low-density, low-resistivity material. The bouguer anomalies also suggest the presence of a steeply-dipping structure bounding the east side of Mesquite Valley.

McKittrick (1983) produced a surficial geologic map of the Nopah and Resting Spring Ranges. Her mapping shows that the youngest surfaces cut by faults are mid to late Pleistocene in age, and possibly in one location, late Pleistocene to early Holocene in age.

PAHRUMP FAULT SYSTEM

GENERAL STATEMENT

The Pahrump fault system (PFS) is divided into three fault zones based on fault geometry, style of faulting, and orientation within each zone (Figure 6, Plate 1). Some mapped faults are transitional between two fault zones and thus no arbitrary boundaries are drawn around the designated fault zones. The right-lateral East Nopah fault zone (ENFZ) is a narrow, linear zone of faults that cuts alluvial fans along the eastern front of the Nopah Range. The right-oblique Pahrump Valley fault zone (PVFZ) lies seven kilometers east of the ENFZ, and extends north into Stewart Valley. The West Spring Mountains fault zone (WSMFZ) splays off the southern end of the PVFZ, and continues north along the Spring Mountains range front. Table 1 summarizes the characteristics of the three zones. Some faults and vegetation alignments do not fit well into any of the three fault zones and will be discussed separately.

On the four 1:24,000 annotated fault compilations (in the back pocket), Quaternary features are described by abbreviated descriptors as shown in the map legend. These features are grouped into categories such as vegetation lineaments, faults or fractures, scarps, etc. Several of the annotations categorize the features by the relative age and type of the deposits that are cut such as VLOP (vegetation lineament in old playa deposits) or SYA (scarp in young alluvium). The units chosen for the compilation maps are broken into four categories in an attempt to add some relative timing information to annotated features. These units are YP (young playa), OP (old playa), YA (young alluvium), and QT (Plio-Pleistocene(?) deposits).

Mapping the surficial deposits in Pahrump and Stewart Valleys was beyond the scope of this study. The units used on the fault compilations were interpreted from aerial photography and are not meant to correspond closely with units mapped by either Malmberg (1967) or McKittrick (1988).

Table 1. Fault zones of the Pahrump Fault System

Name	Length	Sense of Slip	Orientation	Age of youngest geomorphic surface displaced
ENFZ	17 km	right-lateral	N33W	late Pleistocene to early Holocene
PVFZ	50 km	right-oblique	N45W	mid to late Holocene in north, late Pleisto-cene(?) in south
WSMFZ	30 km	normal	arcuate N30W in north N5W in south	late Pleistocene
PFS overall	50 km	dextral shear		as above

The YP (young playa) unit refers to deposits of the modern Pahrump and Stewart Valley playas and/or units in close proximity to the playas that appear to have been deposited in an older and larger playa within the same depocenter. This unit corresponds in part to the Qya or Qp units of Malmberg (1967; Figures 8 and 9). The OP (old playa) unit refers to deposits of an older playa(?) centered in northeastern Pahrump Valley. This unit is inset into the QTol unit of Malmberg (1967), and is currently being dissected by modern drainage into Pahrump and Stewart Valley playas. This unit corresponds in part to the Qya and the QTol units of Malmberg (1967). The YA (young alluvium) unit refers to all of the alluvial fan deposits along the Nopah Range, Resting Spring Range and Montgomery Mountains range fronts as well as the valley floor deposits that could not be clearly designated YP or OP. All of McKittrick's (1988) mapped geomorphic surfaces are formed on the YA unit of this study. The QT (Plio-Pleistocene(?) age) unit corresponds to units mapped as QTol or QTof by Malmberg (1967) and includes any of the older, uplifted deposits within the upthrown block of the PVFZ.

Several of the annotated features on the fault compilations show no associated unit designations. In these cases, the relative ages of the units could not be determined from the aerial photography.

THE EAST NOPAH FAULT ZONE

The East Nopah fault zone (ENFZ), the westernmost fault zone of the PFS (Figure 6, Plates 1 and 2), is confined to the Nopah range front where it lies approximately 0.5 km from the range front. The fault zone terminates to the north in a series of north-trending, left-stepping, east-side-down normal faults (Location 1, Plates 1 and 2). Its southern termination is marked by north-trending, left-stepping, west-side-down normal faults located less than 100 m south of the map area. It is possible that the ENFZ extends northward into Stewart Valley and that a strong vegetation lineament along the west side of the Stewart Valley playa (Location 2, Plates 1 and 5) is an expression of the same fault zone. However, I favor the interpretation that the fault zone terminates at the north end of the East Nopah range front because the fault cannot be traced through Chicago Pass, and no active fault traces occur along the west side of Stewart Valley.

McKittrick (1988) mapped the surficial geology of the Nopah range front. The geomorphic surfaces she mapped are all developed upon the Qyf, Quaternary young fan unit of Malmberg (1967; Figures 8 and 9). McKittrick estimated surface ages based on a combination of time-dependent changes in the surface morphology including drainage density, drainage sinuosity, channel bifurcation, preservation of constructional form, interfluve rounding, pavement development, varnish development, carbonate coatings on surface clasts, quantity of calcrete rubble, and quantity of disarticulated carbonate rinds. She developed a relative age framework that she calibrated by utilizing isotopic age datums for two Pleistocene tephra deposits with the lacustrine strata of the Tecopa Lake basin. These dated tephras, along with an assumed sedimentation rate, allowed her to estimate an age of 300 Ka for the highest lake stand in the Tecopa Lake basin. The high stand shoreline truncates the Qf1 surface and is dissected by the Qf2 surface of McKittrick (1988) along the southwest edge of the Resting Spring Range. This gives a minimum mid-Pleistocene age to the Qf1 surfaces and maximum mid-Pleistocene age to the Qf2 surfaces.

The QTf (estimated as early Pleistocene and/or late Tertiary in age), Qf1 (estimated as mid or early Pleistocene in age) and Qf2 (estimated as late or mid Pleistocene in age) surfaces are cut by several faults of the ENFZ. In one location, McKittrick's (1988) map shows the early Holocene and/or latest Pleistocene Qf3 surface is cut by a fault. However, the low-sun-angle aerial photography analysed for this study shows surface Qf2 to be the youngest surface cut by a fault. Thus, the youngest surface that may be cut by faults of the ENFZ (Qf3) is estimated as early Holocene to late Pleistocene in age (McKittrick, 1988) and her estimated mid to late Pleistocene surfaces are cut by several faults.

Expression on Aerial Photography

On aerial photography, the ENFZ shows a straight, linear, narrow (generally <200 m wide) trace with several more northerly oriented subparallel splays that lie generally to the southwest of the main fault trace. The faults can be traced continuously for over 15 km along and subparallel to the eastern Nopah range front, except where they are buried by the younger (early to late Holocene) alluvial fan deposits. The fault zone is geomorphically expressive, that is, many scarps, fault lineaments and offset surfaces are easily observed on the aerial photography. In general, the fault zone consists of several closely spaced, discrete faults that are in some cases subparallel, and in others braided and anastomosing in map view. In several locations, closely spaced faults are so numerous that the fault zone appears to be a narrow, pervasively sheared zone. In at least three locations, (Locations 3 and 4, Plates 1 and 2 for example), major splays branch off the west side of the main fault toward the southwest. Here, the fault zone widens to up to 1 km.

The fault scarps have generally low relief, and in many places, no fault scarps are observed on the aerial photography. In these locations, the faults are expressed as fractures or cracks in the strongly carbonate-cemented surfaces, and show up as dark, discrete lines on the aerial photographs. In other places, the faults offset calcrete surfaces forming horsts, grabens, and low hills interpreted to be erosion-resistant alluvial fan remnants squeezed up or dragged in along the fault. Probable laterally offset fan remnants are juxtaposed along fault scarps that face both east and west. The west-facing scarps have caused alluvium to pond upfan from the scarp, as in Location 5. Fault traces remain straight and linear even where they cut across alluvial washes or raised fan remnants, indicating that the faults are nearly vertical. Figure 11 is an aerial photograph that exemplifies this linear surface expression.

In several locations, offset and/or deflected drainages have been observed on the aerial photography. The apparent offsets are dominantly (but not consistently) right-lateral. Some of these may be drainages deflected along zones of weakened fault rocks rather than offset drainages. On Plate 2, designations for deflected drainage (dd) and offset drainage (od) are subjective, based only on interpretation of aerial photography.

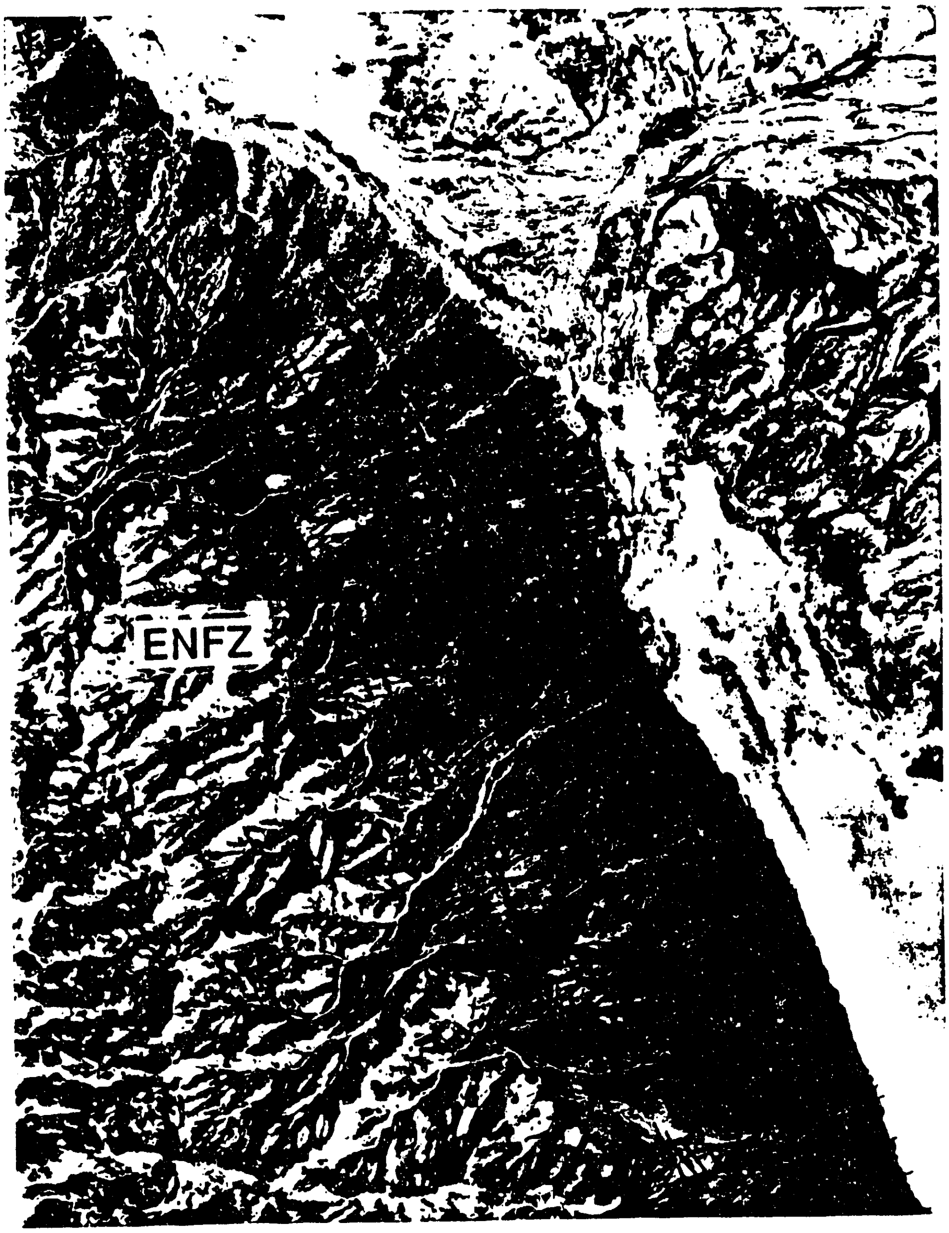


Figure 11. A 1:80,000 scale aerial photograph showing the straight linear trace of the East Nopah fault zone.

Outcrop Expression

Field examination of several faults of the ENFZ showed that in all cases, faults exposed in cutbanks dip at very high angles and in nearly all cases these faults are vertical. Figures 12 and 13 are photos of outcrops at locations 6 and 7 (Plates 1 and 2). The zone of disruption along any given fault is generally several meters wide and is defined by disrupted alluvial fan stratigraphy and by multiple fault surfaces impregnated with secondary carbonate. In some cases, a fault is marked by a single, narrow zone a few centimeters wide that is impregnated with secondary carbonate.

Stratigraphic units in the alluvial fan deposits do not match across fault traces. The alluvial fan deposits are discontinuous bodies of angular, clast supported gravel that cannot be traced laterally for any great distance, and are separable only by changes in clast size within each body. In many cases, the gravels have been impregnated by secondary carbonate to such an extent that the original stratigraphy is obscure. No slickensides or other indicators of slip direction were observed in fault outcrops. Measured fault orientations agree with the overall orientation of the ENFZ, and due to the nearly vertical fault plane orientations, trends of mapped fault traces are good approximations of actual fault orientations.

Figure 12. Outcrop expression showing the subvertical dip of a fault within the East Nopah fault zone (Location 6, Plates 1 and 2).

Figure 13. Several vertical faults of the East Nopah fault zone exposed in a cutbank. (Location 7, Plates 1 and 2).

Surficial Features

Low-sun-angle aerial photographs were examined for evidence of offset geomorphic features. Several deeply incised drainages show apparent lateral offsets at the fault trace, but these are probably deflections of the stream channel along the more easily eroded fault zone, since the apparent offsets occur in both a left-lateral and right-lateral sense. Two possible right-lateral offsets of stream channels that are visible on low-sun-angle aerial photographs (locations 8 and 9, Plates 1 and 2) could not be confirmed in the field, as the drainages on the upfan side of the faults could not be located precisely. Thus, none of the channel offsets were confirmed in the field.

Air photo analysis and field mapping for this project, and the surficial geologic map of McKittrick (1988) show that geomorphic surfaces developed on alluvial fans of differing ages are juxtaposed across the ENFZ (Figure 14; Location 5, Plates 1 and 2). The mapping of the present study shows that these fan remnants are cut by both east-facing and west-facing scarps. In general, west-facing scarps appear steeper and higher than east-facing scarps because west-facing scarps have been enhanced by fluvial erosion while east-facing scarps have been subdued by fluvial erosion. Both sheetwash and confined drainage of the alluvial fan surface flows downslope to the east. Down

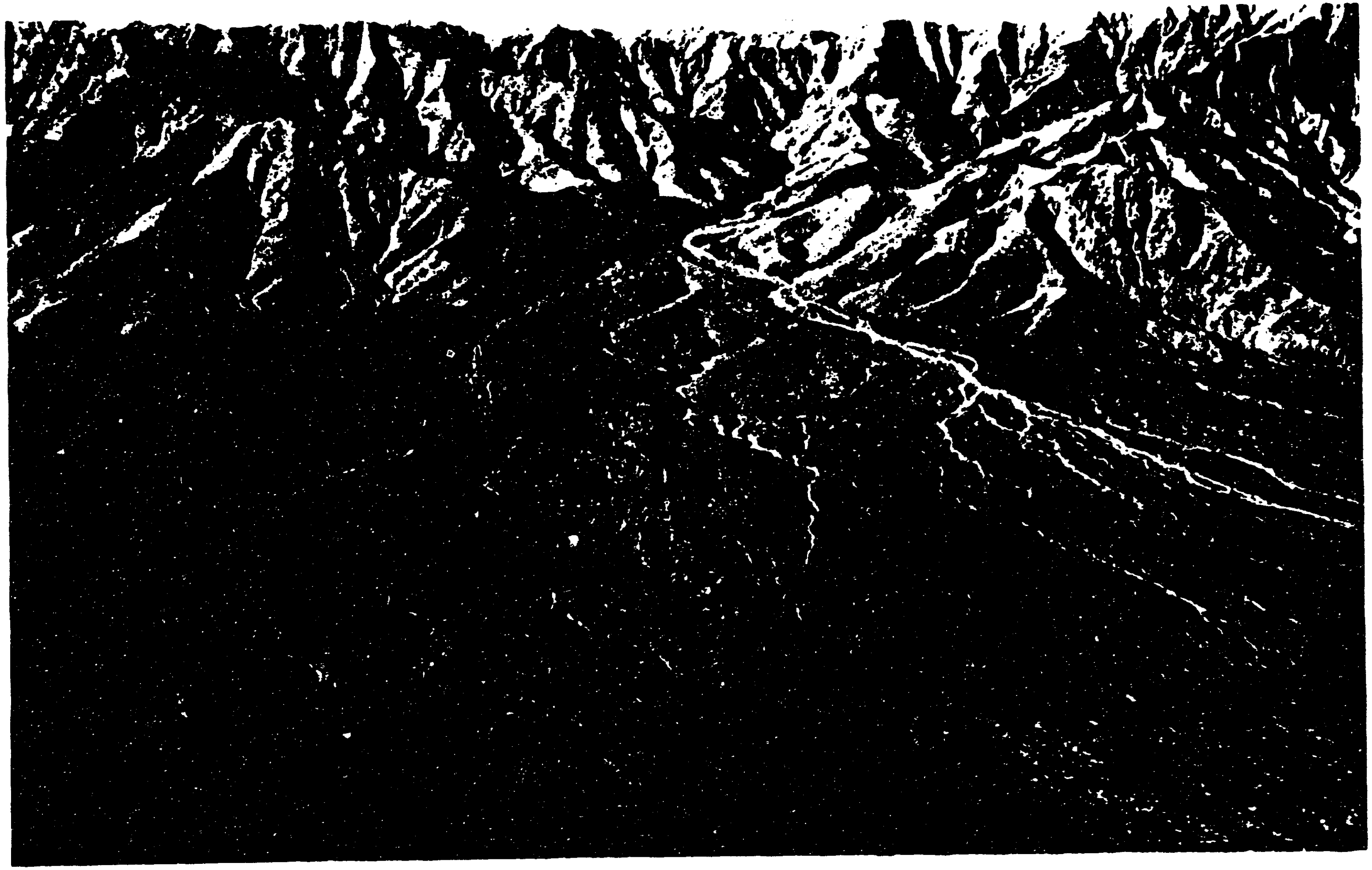


Figure 14. Alluvial fan remnants of varied ages juxtaposed along the East Nopah fault zone (Location 5, Plates 1 and 2). The arrows mark the main fault trace. Several different age fan remnants can be seen on either side of the main fault.

gradient flow is hindered by west-facing scarps where water ponds and drainage is deflected causing erosion at the base of the scarp. Water flows over the crest and down the face of east-facing scarps, causing accelerated degradation of the scarp slope.

Scarps associated with faults that juxtapose older fan remnants against younger fan remnants are steeper, higher and much easier to locate in the field. Fault scarps in the QT surfaces (Quaternary-Tertiary surfaces of McKittrick, 1988) have up to 8 m vertical relief. This may either be due to the older surfaces having larger offsets produced by a longer history of fault movement, or, more likely, due to the fact that older, strongly cemented fan deposits stand in higher relief than weakly cemented younger deposits.

In several locations, the drainages have headcuts up to 3 m high that coincide with active fault traces. These headcuts always occur in carbonate cemented pedogenic horizons.

Fault Patterns

A structural analysis of the fault patterns of the ENFZ is presented. The overall fault patterns of the ENFZ is strikingly similar to the fracture patterns of the Dasht-e Bayaz earthquake as presented by Tchalanko and Ambraseys (1970). Their study analysed fracture patterns from the

Dasht-e Bayaz earthquake based on Coulomb failure criterion applied to a material with an angle of shearing resistance of 35° to 40°. The fractures they analysed were contained within Quaternary alluvium as are the young faults of the ENFZ. In the case of simple shear, the Coulomb failure criterion predicts that the orientations for Reidel shears, conjugate Reidel shears, P shears and tension gashes for a material with an angle of shearing resistance of ϕ are as shown in Figure 15 (Tchalanko and Ambraseys, 1970). See Tchalanko and Ambraseys (1970) for further explanation.

The overall trend of the ENFZ is N33°W. The southern 9 km of the fault zone is marked by five en echelon segments trending between N16°W and N30°W (mean N25°W). Each en echelon segment terminates at an area where the fault zone broadens, and where faults that trend more northerly, from N18°W to N8°E (mean N3°W) splay to the southeast off the main fault zone, toward the Nopah Range (Locations 3 and 4, Plates 1 and 2 for example). The lengths of en echelon segments range from 3 to 1.8 km (mean 2.45 km).

The angle between the mean trend of the en echelon faults and the overall trend of the fault zone is ~8°, less than the 15° deviation predicted for synthetic Riedel shears in a material with an angle of shearing resistance taken to be 30°. However, the en echelon segments are best interpreted as Riedel shears and their orientation 8° in a clock-

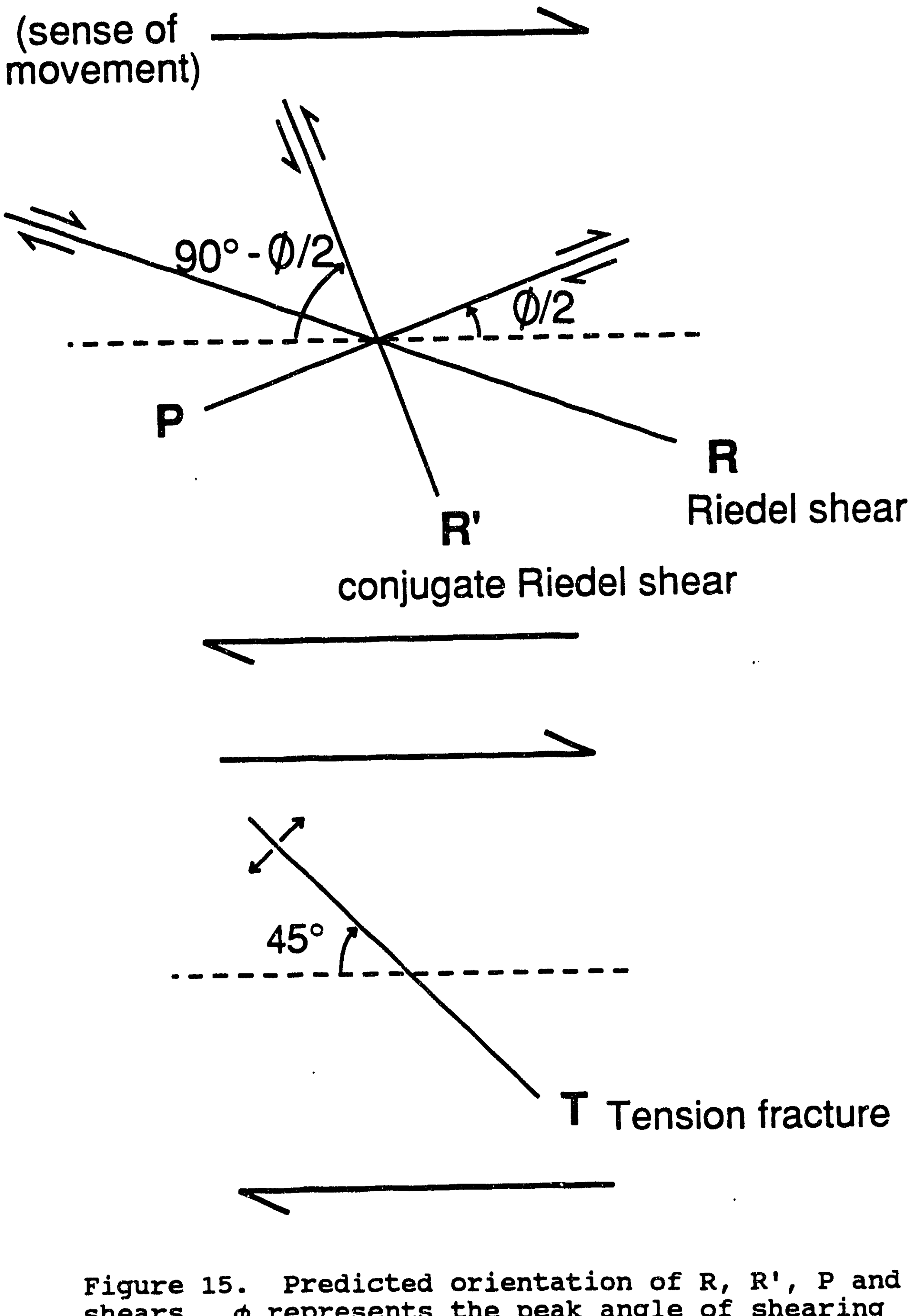


Figure 15. Predicted orientation of R, R', P and T shears. ϕ represents the peak angle of shearing resistance. (Modified from Tchalenko and Abraseys, 1970).

wise sense from the trend of the main fault zone, together with their left-stepping pattern suggest right-lateral displacement across the ENFZ.

The trends of the smaller faults, fractures and lineaments (those not a part of the main trace of the ENFZ) were measured. A rose diagram of these trends was developed by measuring the orientation of the minor faults and lineaments, as well as the orientation of individual fault segments along the same fault where they are separated by a major change in strike along one fault trace. This plot is shown in Figure 16. This figure shows that the smaller faults within the ENFZ have two dominant orientations, one about N25°W and the other about N5°E. The N25°W-trending faults are aligned with the en echelon faults along the southern part of the ENFZ. This fault set may also represent synthetic Riedel shears. The N5°E-trending fault set is oriented at a 38° angle to the main ENFZ. These more northerly oriented faults may be tension gashes.

At the northern termination of the southernmost en echelon fault segment, at Location 7 on plates 1 and 2, a graben has formed where the fault has a slightly more northerly trend (about 12° north of the main trend of the fault segment). This may suggest that the more northerly trending faults have an extensional component and may support the interpretation that these faults may be tension gashes.

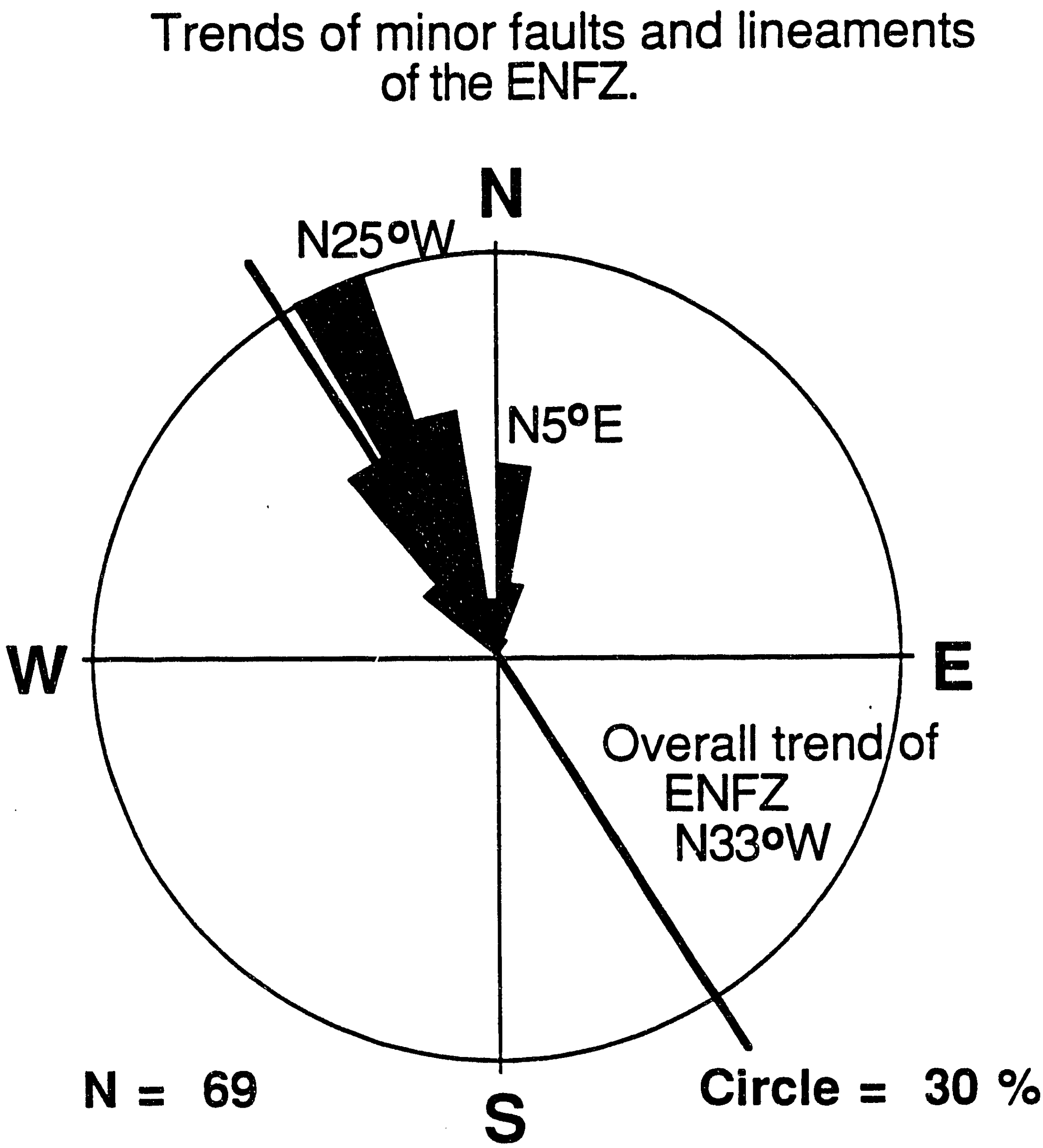


Figure 16. Rose diagram showing two dominant fault and lineament orientations along the ENFZ.

Approximately one kilometer east of the main ENFZ is a second zone of faint lineaments that is subparallel to the ENFZ. About 1.5 km east of these faint lineaments, a linear contact of the Nopah range alluvial fans with the Pahrump playa may represent a third zone of faulting. Thus, there may be at least two subparallel subsidiary faults lying east of the main trace of the ENFZ.

At the northern termination of the ENFZ, a late Pleistocene fan surface is offset along three north-trending faults (Location 1, Plates 1 and 2). These scarps are oriented ~N7°E to ~N20°W and have east-side-down offsets except for a small, graben-bounding west-side-down fault. These may be minor tension gashes that terminate the zone of strike-slip displacement.

If the N33°W trending trace of the ENFZ is considered to be the main fault zone, the N16-30°W trending Riedel shears and a possible set of northeast-trending tension gashes are broadly consistent with a right-lateral, strike-slip fault zone as predicted for right-lateral strike-slip faults (Figure 15; Tchalenko and Abraseys, 1970).

Interpretation of Displacements

The ENFZ exhibits an anastomosing and braided pattern in some places, and a subparallel pattern in others. The left-stepping en echelon fault segments along the southern part of the ENFZ, the possible tension gashes represented by grabens and normal faults, and horst-like pieces of fans that are pushed up between braided fault strands, all support a right-lateral strike-slip interpretation for movement on the ENFZ.

From these lines of evidence the ENFZ is best interpreted as a strike-slip fault. The fault patterns discussed earlier and the similar orientation of the ENFZ to the right-lateral Furnace Creek and Fish Lake Valley fault zones also suggest that the fault should be right-lateral.

Recency of Activity

McKittrick's (1988) mid to late Pleistocene fan surfaces mapped as unit Qf2 are cut by abundant faults and fractures. These surfaces have a well-preserved constructional form. Drainage patterns that originate on the fan surfaces range from subparallel to subdendritic and are largely confined to steep sided, highly sinuous, U-shaped channels that are typically less than 5 m deep. Interfluves are broad and flat and display well-developed, tightly interlocking stone pavements. Clasts coated with secondary carbonate range in abundance from 10-60% total surface clasts. Carbonate rinds on surface clasts are typically less than 1 cm thick and detached rinds constitute less than 5% total surface clasts.

The absence of measurable offset on young geomorphic features and the absence of faults on the younger, early to late Holocene surfaces (McKittrick, 1988) together indicate that the youngest faulting event was probably mid to late Pleistocene in age. However, strong en echelon vegetation lineaments in youngest Holocene sediments along the northwest edge of the Pahrump playa (location 10, Plates 1 and 2) may indicate some mid to late Holocene activity occurred on faults buried beneath the late Holocene(?) playa sediments.

Qualitative analysis of fault scarps along the rangefront is equivocal. Scarps appear distinct on aerial photography, and subdued in the field. However, many faults cut surfaces that have thick pedogenic carbonate horizons that are resistant to erosion, and thus scarp morphology is of little value in determining recency of fault activity. A further complication is that the faults may have had primarily strike-slip displacements, and therefore many of the scarps may be related to lateral juxtaposition of geomorphic surfaces of differing resistance to erosion. Apparent vertical separations cannot be considered to be true vertical offsets.

A determination of precise slip-rates is not possible because none of the surfaces displaced by the East Nopah fault zone have been dated. However, a crude estimate of vertical slip on one of the north-trending normal faults can be calculated by assuming a surface with a three meter high scarp is 500 to 50 Ka (mid to late Pleistocene age as mapped by McKittrick, 1988). This would yield vertical slip rates of 0.06 - 0.6 mm/yr. This slip rate applies to one of the more northerly trending fault segments, and the ratio of vertical to lateral movement is unknown.

Summary

The ENFZ is interpreted to be a right-slip fault zone. This interpretation is supported by the following lines of evidence: 1) a lack of major topographic expression across the fault, 2) a nearly vertical fault plane in most exposures, 3) juxtaposition of different age fan surfaces across the fault zone, 4) scarps that face both east and west, 5) a nearly straight fault trace, 6) a narrow fault zone that cross-cuts topography, 7) northern and southern terminations of the fault zone that occur along a series of north-trending normal faults, 8) minor faults and lineaments oriented at a small angle to the main fault zone that resemble Riedel shears, and minor faults and lineaments oriented 38° to the main fault zone that may represent tension gashes, and 9) a trend similar to that of other right-lateral faults such as the Furnace Creek and Fish Lake Valley fault zones. The most recent activity of the ENFZ shows no evidence for a component of normal-slip along the ENFZ.

THE PAHRUMP VALLEY FAULT ZONE

The Pahrump Valley fault zone (PVFZ), over 45 km long and 6 km wide, lies approximately along the California-Nevada state line, 7 km east of the ENFZ (Figure 6, Plates 1 through 5). The southern part of the PVFZ, south of latitude 36° 05' N (Plates 1 and 4), is marked by two prominent, subparallel and continuous strands with a general trend of N45°W. The westernmost trace is represented by an alignment of low hills of resistant alluvial fan deposits (Figure 17). The eastern trace is marked by an escarpment that lies 2.5 km east of the low hills (Figure 18). In northern Pahrump Valley, north of latitude 36° 05' N, these two traces die out (Plates 4 and 5) and the PVFZ is a broad zone of low scarps and vegetation lineaments. Some of these features continue north along the eastern side of Stewart Valley, north of Highway 178 (Plates 1 and 5).

The southern boundary of Plates 1 and 2, and the southeastern boundary of Plates 1 and 3, reflect the limits of aerial photography available for this study. However, the PVFZ continues southeast for some distance, but apparently dies out north of Mesquite Valley, where MIT's Field Camp (1985) reported a lack of scarps. Very-high altitude Landsat Thematic Mapper imagery shows what appear to be scarps and/or vegetation lineaments at least as far southeast as Black Butte (Figure 1).

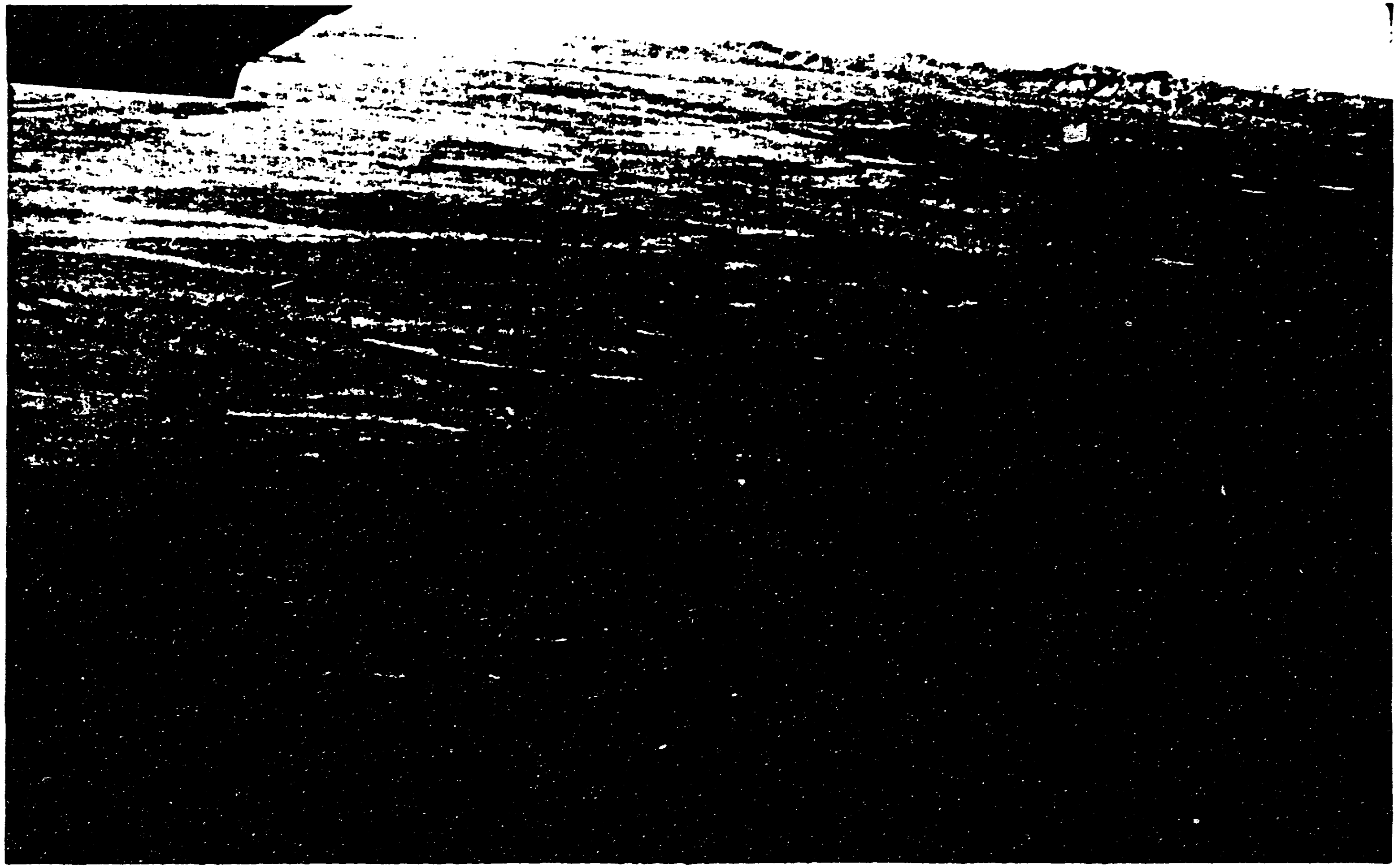


Figure 17. An alignment of cemented alluvial fan deposits and spring mounds that represent the westernmost trace of the southern PVFZ. View looks south.

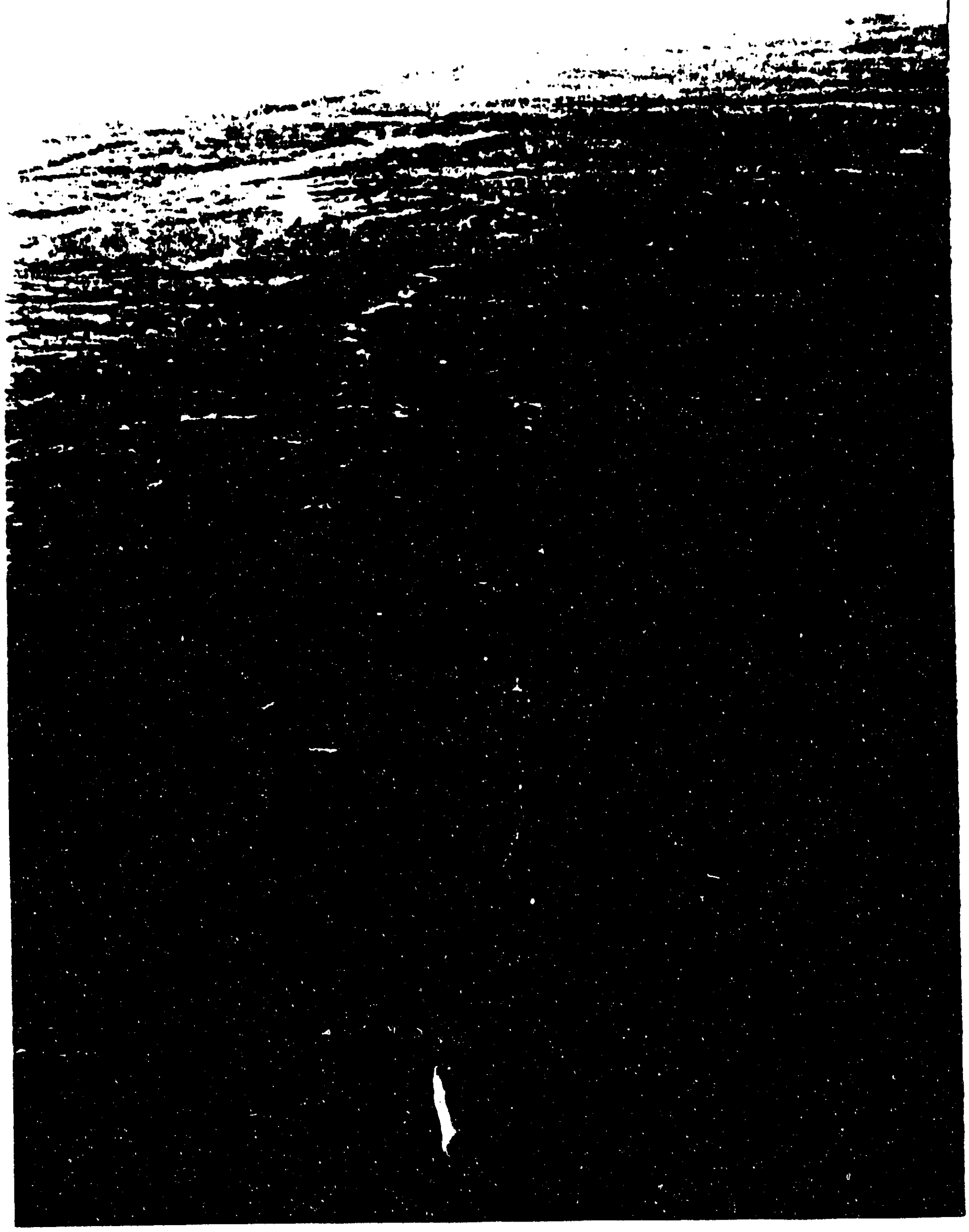


Figure 18. The eastern or 'main' trace of the southern part of the PVFZ. The scarp is approximately 12 m high. View to the south.

Southern part of the PVFZ

In the southern part of Pahrump Valley, south of latitude 36° 05' N (Plates 1 and 4), the PVFZ consists of two subparallel traces trending N45°W, and several splays off the north side of the fault that trend approximately N14°W (Plates 1, 3 and 4). The western fault trace is marked by hill-forming erosional remnants of cemented alluvial fan deposits (Qof of Malmberg, 1967; Figure 17). Along this trace, just down drainage from Browns Spring (Location 11, Plates 1 and 3), one well-defined fault cuts through the old alluvial fan deposits, with the upthrown block to the east.

The main fault trace lies 2.5 km east of the western trace, where Plio-Pleistocene(?) strata are uplifted and tilted up to 14° to the east, and exposed along an 8-15 m high escarpment. On the upthrown block, an extensive plateau region representing an old erosional surface has been dissected by drainages that form narrow deep canyons. The uplifted Plio-Pleistocene(?) section is capped by a resistant freshwater siliceous limestone along the main escarpment. The main escarpment and several escarpments farther east within the upthrown block are highly eroded and sinuous (Figure 18), indicating that major movement has not occurred for some time along these faults.

At Stump Spring (just south of the southern map boundary), Browns Spring (Location 11, Plates 1 and 3; Figure

19), Hidden Hills Ranch (Figure 2) and several other locations, springs have flowed in historic times. These springs probably originated from artesian aquifers exposed by faulting since several of the springs are aligned along the southern part of the eastern escarpment of the PVFZ. Excessive pumping of ground water in historic time has halted the flow of these springs. Spring flow may have been responsible for much of the dissection of the main PVFZ escarpment, but storm runoff probably also has played a significant role. Stream dissection on the pediment surface between the two major fault traces is also significant but not as extensive as above the main escarpment. Figure 19 is a 1:12,000 scale low-sun-angle aerial photograph of the Browns Spring area (Location 11, Plate 1) located on the photo. This photo shows the extreme dissection of both the upthrown and downdropped sides of the faulted pediment surface. In this area, the main escarpment of the PVFZ has a maximum height of 15 m.

The Browns Spring drainage shows complex stratigraphic and geomorphic features. A traverse from Browns Spring downstream through the incised canyon reveals a complex stratigraphy where younger, fine-grained lacustrine and\or paludal and fluvial deposits are inset into the older, uplifted Plio-Pleistocene(?) section (Figure 20). Though the age of the inset deposits is unknown, they were de-

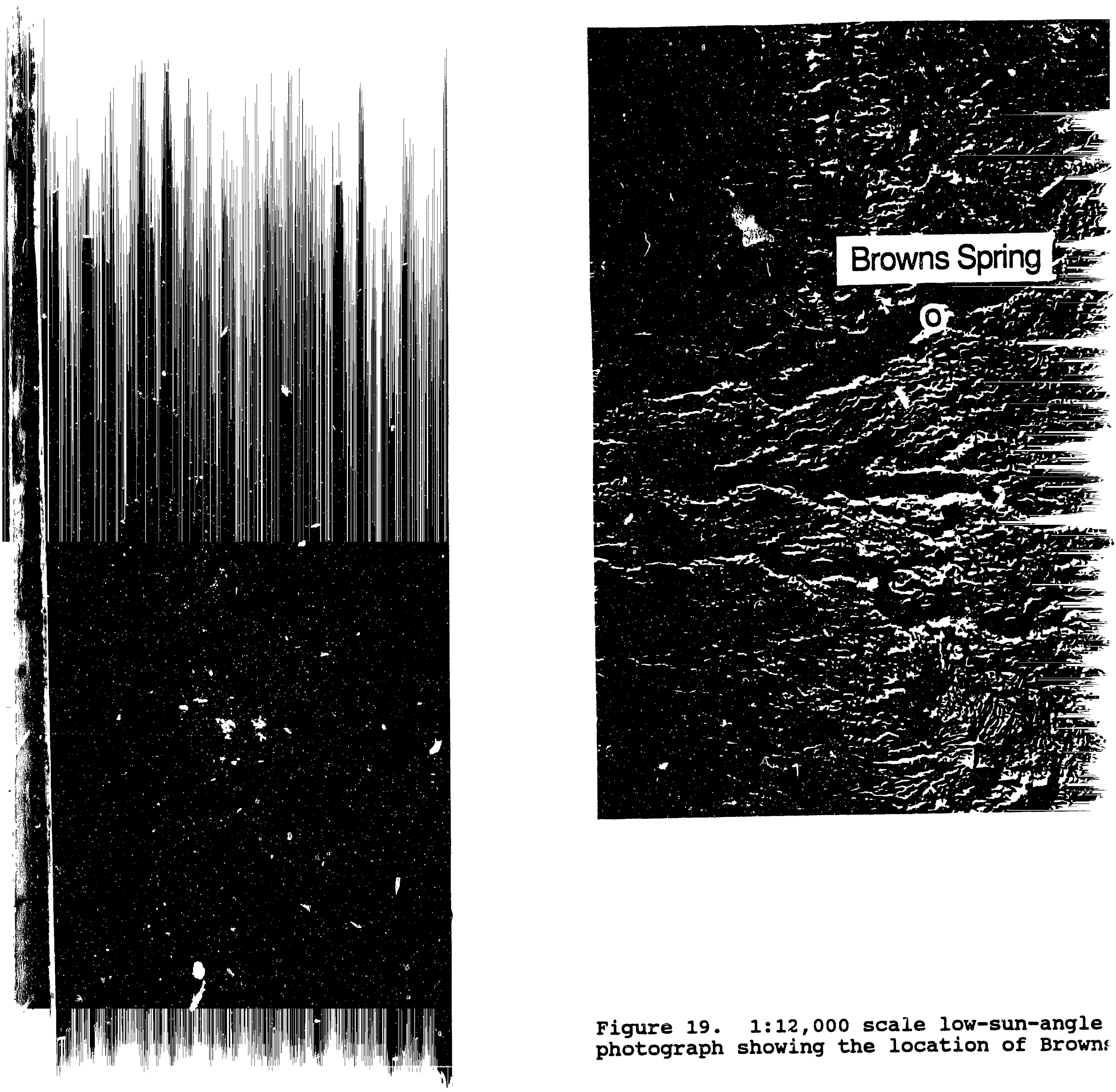
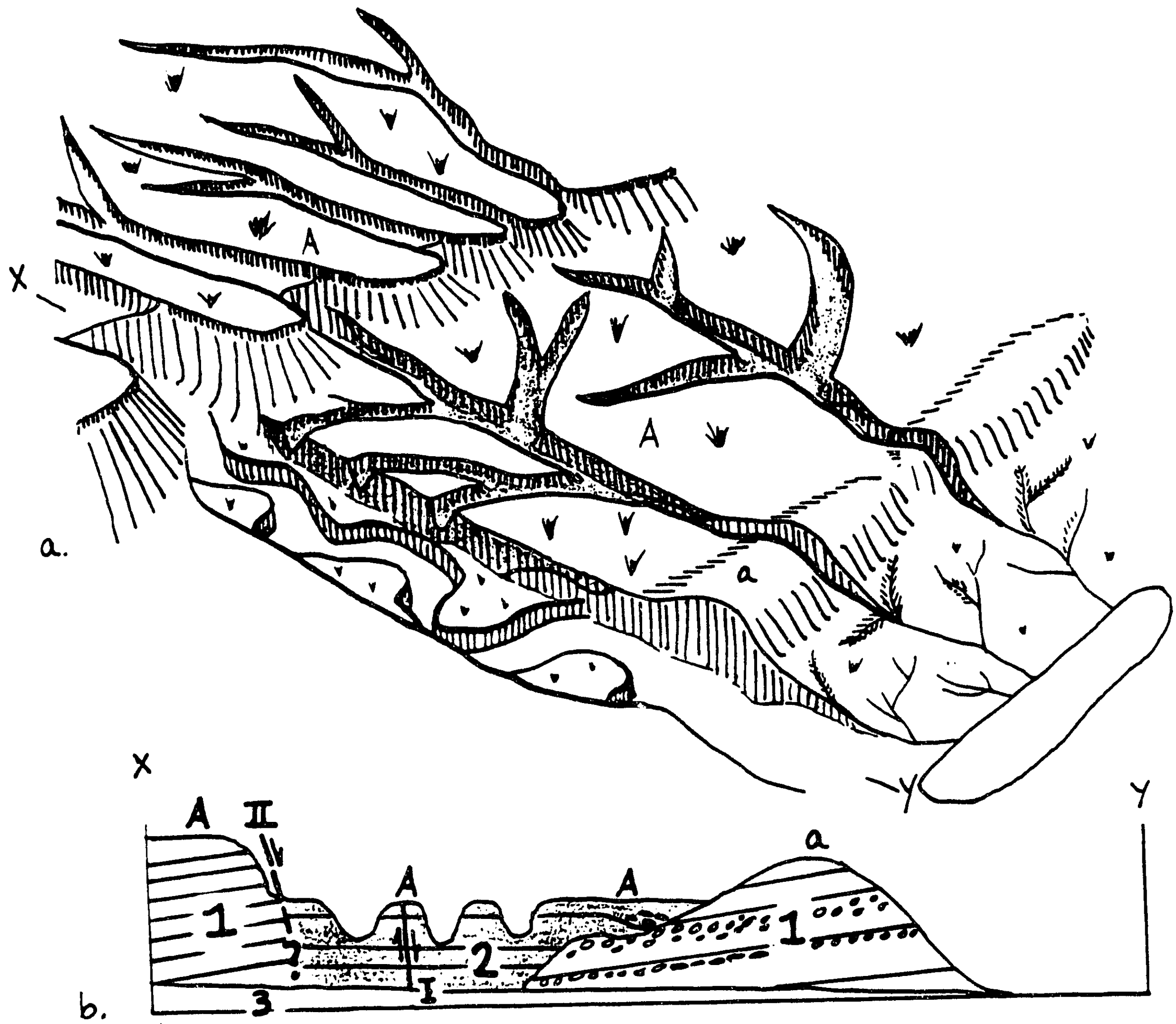


Figure 19. 1:12,000 scale low-sun-angle
photograph showing the location of Browns



1. Deposition of Unit 1.
2. Back-tilting of Unit 1.
3. Deposition of Unit 2 inset into Unit 1. Eastern contact may be fault controlled (Fault shown as fault event II may have had movement prior to deposition of Unit 2).
4. Fault Event I (sense of offset unknown).
5. Formation of pediment A. Possible contemporaneous formation of erosional remnant a.
6. Fault event II offsets pediment.
7. Erosional downcutting of channel through units 1 and 2.
8. Deposition of inset Unit 3 begins ~1000 Ma. Unit 3 is not faulted.
9. Drop in base level west of cross section by either west-side-down faults or synformal folds causing stream incision into pediments and inset deposits (unit 3).

Figure 20. Diagrammatic cartoons showing stratigraphic and fault relationships exposed within the Browns Spring drainage. a. View is to the east-southeast. b. View is to the south-southeast.

posited prior to formation of the pediment surface and were involved in an earlier episode of faulting. The pediment is downdropped along the main escarpment. Deposits within an unfaulted, inset terrace in the Browns Spring drainage have been radiocarbon dated at 880 +/- 50 years (J. Quade, pers. comm., 1989) near the base of the deposit (Figures 20 and 21).

Near the drainage headcut just south of Browns Spring, (Location 12, Plates 1 and 3) a fault exposed in the Plio-Pleistocene(?) section has sharply upwarped the bedding over a distance of 10-15 m to a maximum dip of 24^{o} east (Figure 22). This fault offsets a biotite-rich tuff, which is currently being dated. This same fault is exposed in an incised drainage 0.5 km south of Browns Spring, where it is vertical (Figure 23). In the southern exposure, bedding dips less than 15^{o} away from the fault on either side, and units cannot be stratigraphically correlated across the fault. The overall trend of this fault is N41^{o}W.

The Browns Spring drainage cuts through a low hill along the western trace of the PVFZ and exposes 5^{o} east-dipping alluvial fan deposits. A fault graben exposed in this fan just down drainage from Browns Spring (Location 11, Plates 1 and 3) is less than two meters wide by two meters deep and is buried by unfaulted terrace deposits. Several faults and fractures near the graben have an orientation

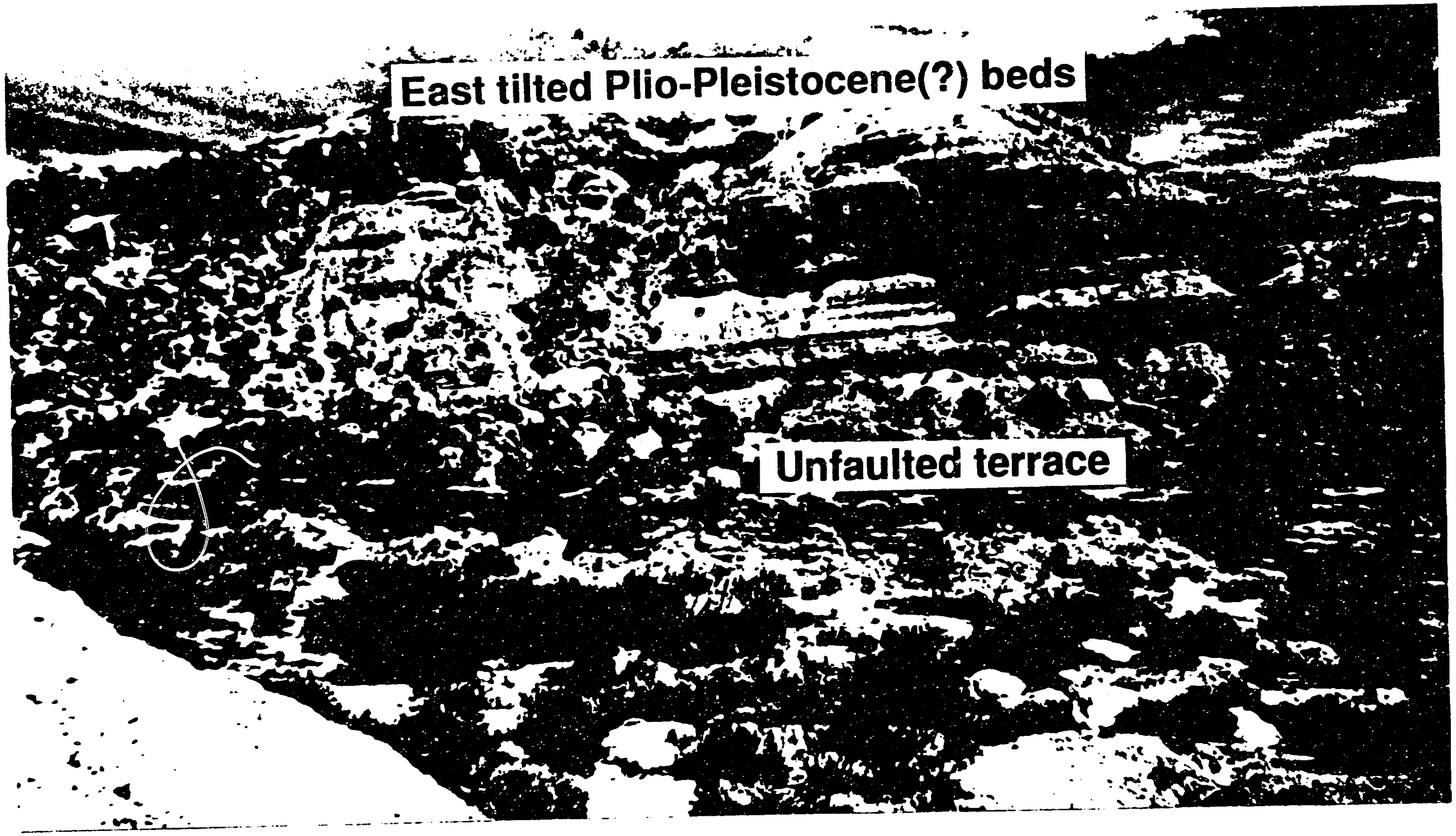


Figure 21. Unfaulted inset terrace at Browns Spring. View looks south. The vertical cutbank in the background exposes east-tilted Plio-Pleistocene(?) age strata (Qol of Malmberg, 1967). An inset fluvial terrace dated at 880 +/- 50 years (in foreground) shows no evidence of faulting.

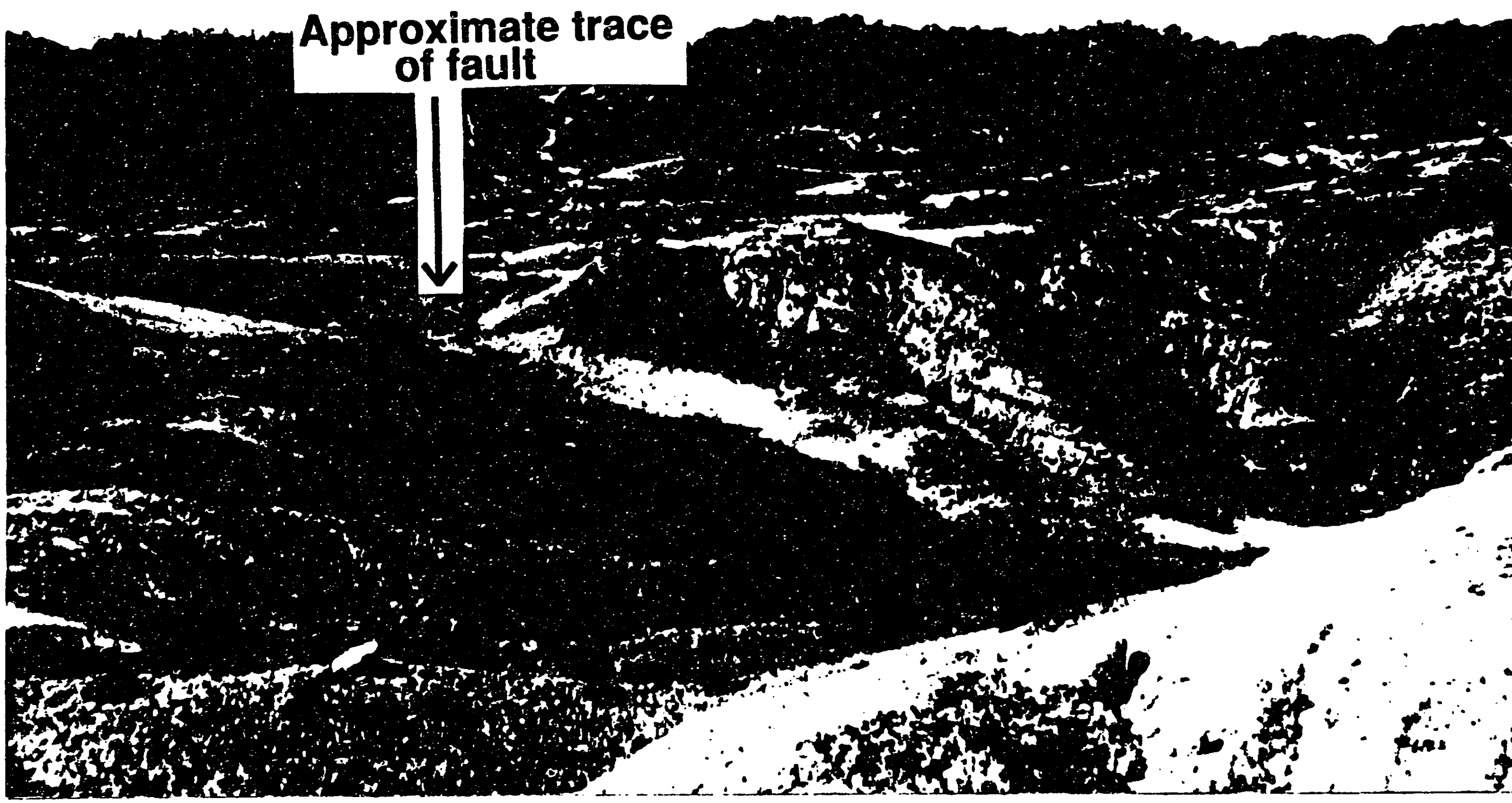


Figure 22. Upwarped bedding along a nearly vertical fault exposed at Browns Spring. The inferred fault passes to the left (west) of the upwarped beds. View is to the north.

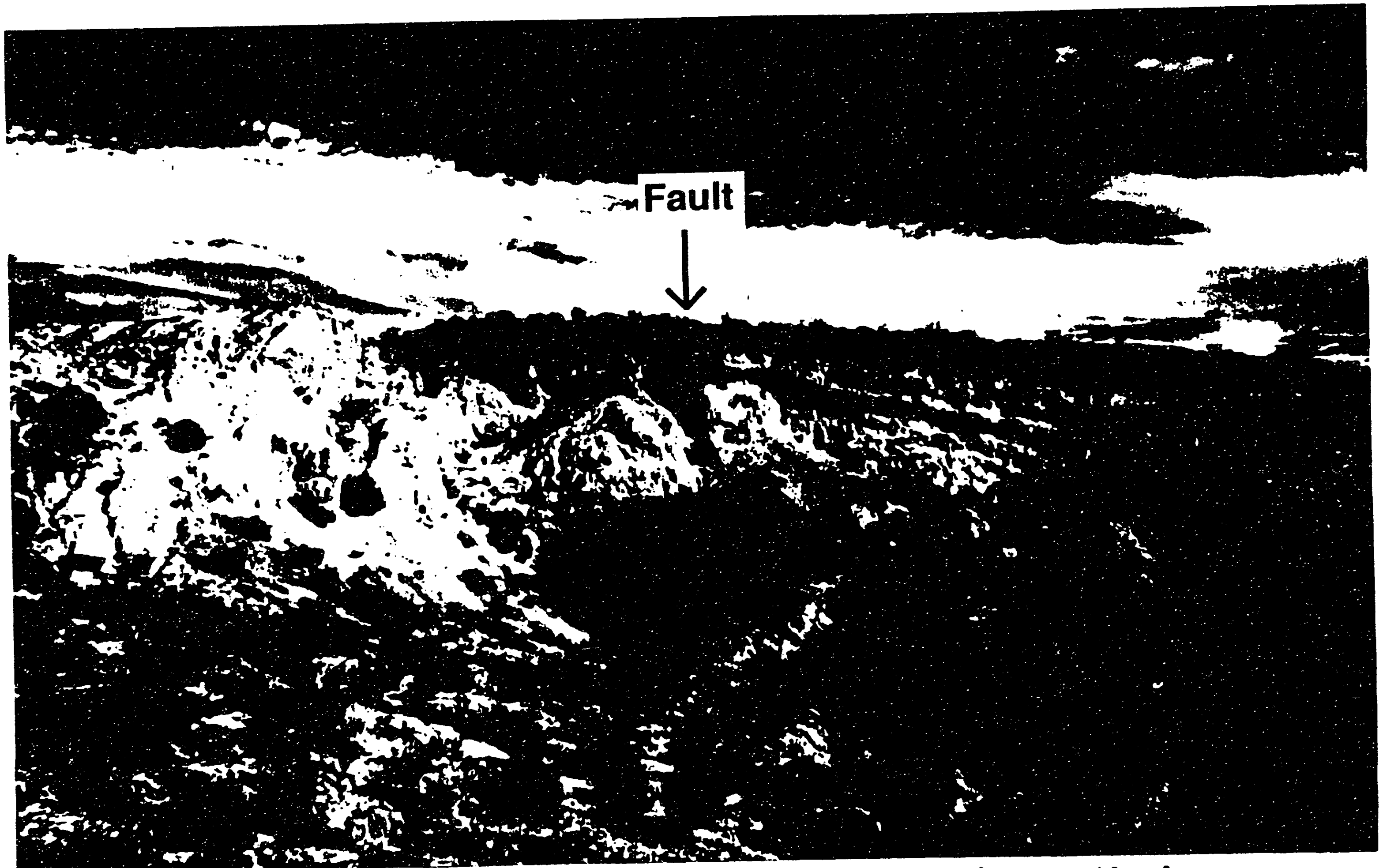


Figure 23. Nearly vertical fault exposed in a cutbank near Browns Spring. Bedding dips <15° away from the fault on either side. This is the same fault inferred in Figure 22. View is to the south.

of N50°W with steep to vertical east and west dips.

Fan stratigraphy includes abundant cobble-rich debris flow deposits interbedded with fluvial tuffaceous sandstones. Cobble lithologies include green tuffs, probable Jurassic siltstones (M. Carr, pers. comm., 1990), abundant limestones including Mississippian Monte Cristo limestone(?) (M. Carr, pers. comm., 1990), and sparse vesicular basalts. These cobbles may reflect a source area in the southern Spring Mountains.

North of Browns Spring, the main PVFZ escarpment decreases in height, dying out near Location 13, Plates 1 and 3. Much of the escarpment north of Browns Springs is buried by stable, vegetated sand dunes of probable Holocene age. These dunes do not appear to be cut by faults.

Northern part of the PVFZ

Scarps and vegetation lineaments are widely distributed along the northernmost part of the PVFZ, north of latitude 36° 05' N to southeast of Stewart Valley (Figures 24, 25, and 26; Locations 14 and 15, Plates 1 and 4). Many faults are developed in upper Quaternary(?) playa sediments (Unit Qya of Malmberg, 1967) and the morphology of the scarps suggests that they are late Pleistocene to Holocene in age. Figures 27 and 28 are scarp profiles across some of the younger fault traces at Locations 14 and 15, Plates 1 and 4.

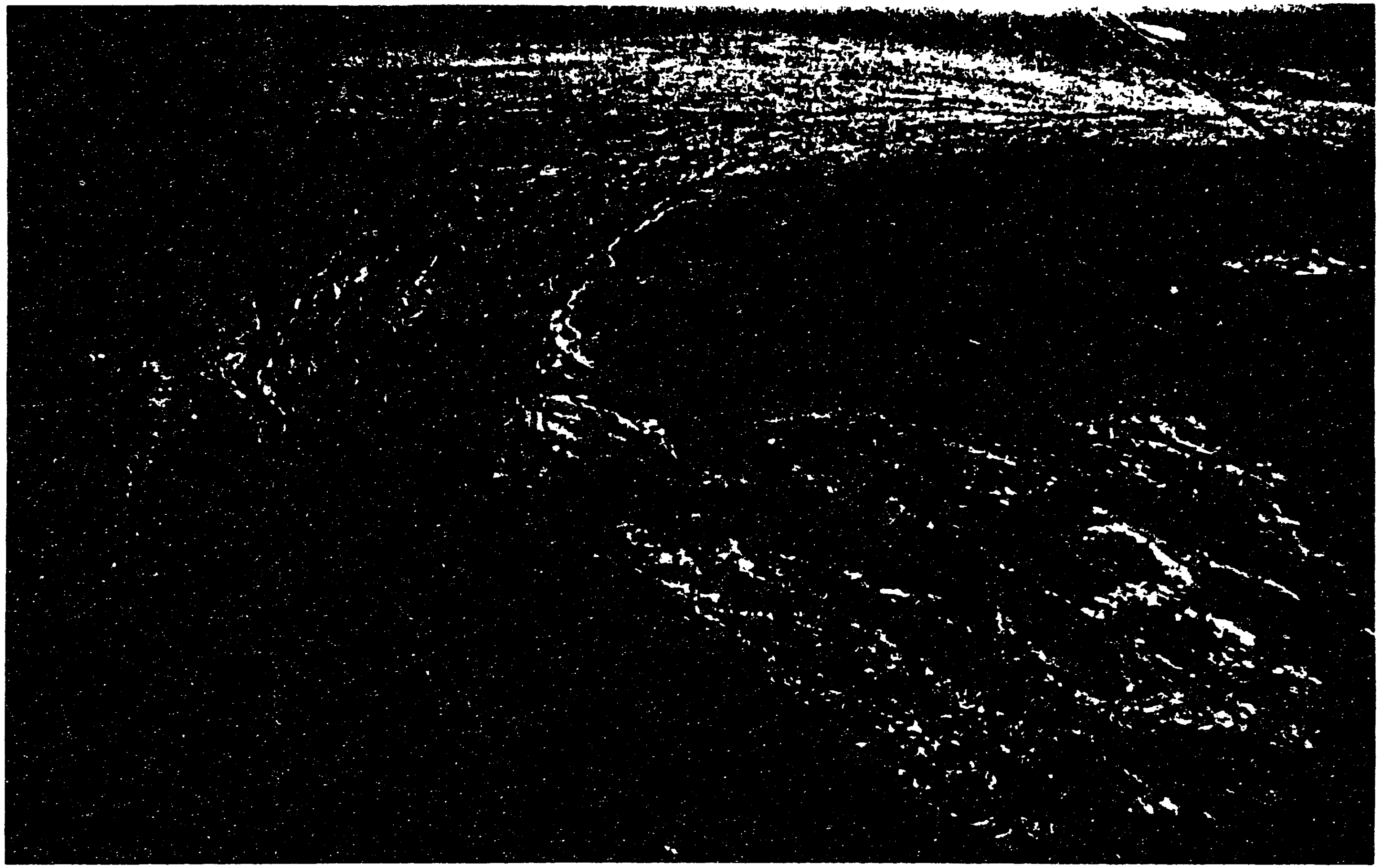


Figure 24. A young fault scarp along a splay of the Pahrump Valley fault zone cutting Unit Qya of Malmberg (1967) or the old playa (op) unit of this report. View to the northwest. (Location 14, Plates 1 and 4).

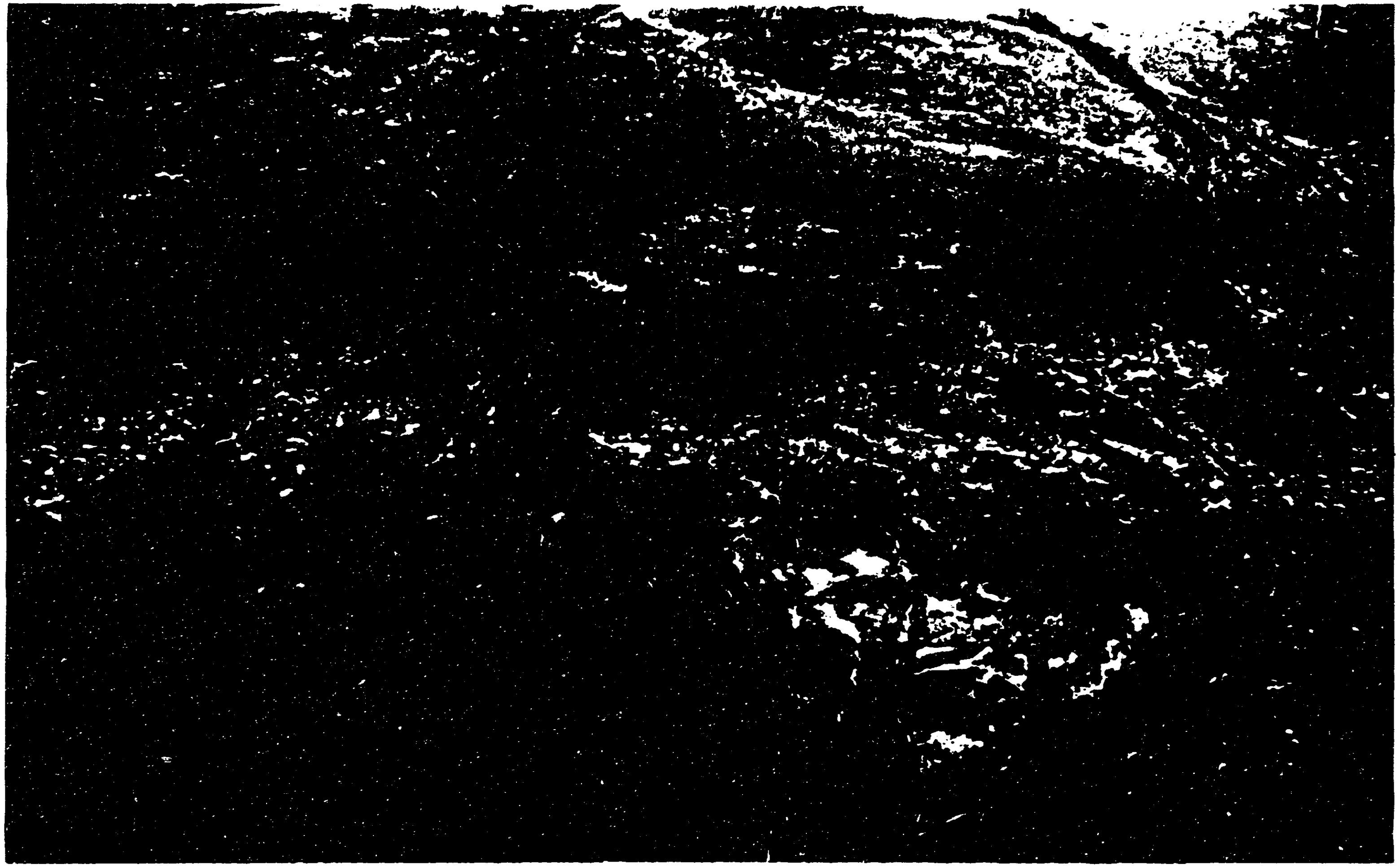


Figure 25. A young fault scarp along a splay of the Pahrump Valley fault zone cutting unit Qya of Malmberg (1967) or the old playa (op) unit of this report. View to the east. (Location 16, Plates 1 and 4).

Figure 26. A young fault scarp along a splay of the Pahrump Valley fault zone cutting the Qya unit of Malmberg (1967) or the old playa unit (op) of this report. The base of the scarp trends from the middle left side of the photo and crosses to the lower right side of the photo. The top of the scarp crosses from left to right in the center of the photo. Note person on top of scarp at right for scale. View to the northeast. (Near Location 14, Plates 1 and 4).

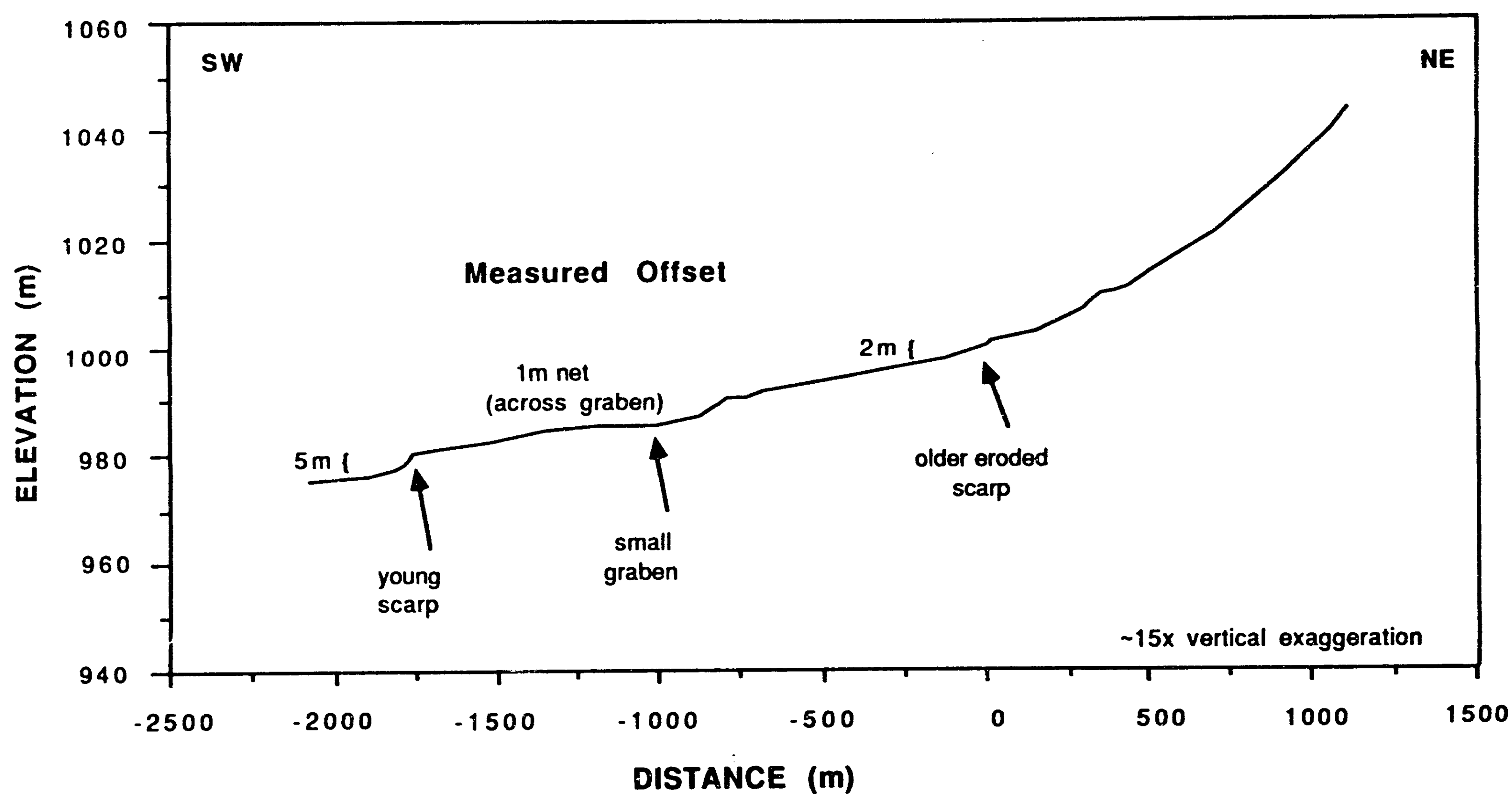


Figure 27. Scarp profile across three fault splays along the northern part of the Pahrump Valley fault zone. The scarps show a progressively younger morphology from right to left. (Location 15, Plate 4).

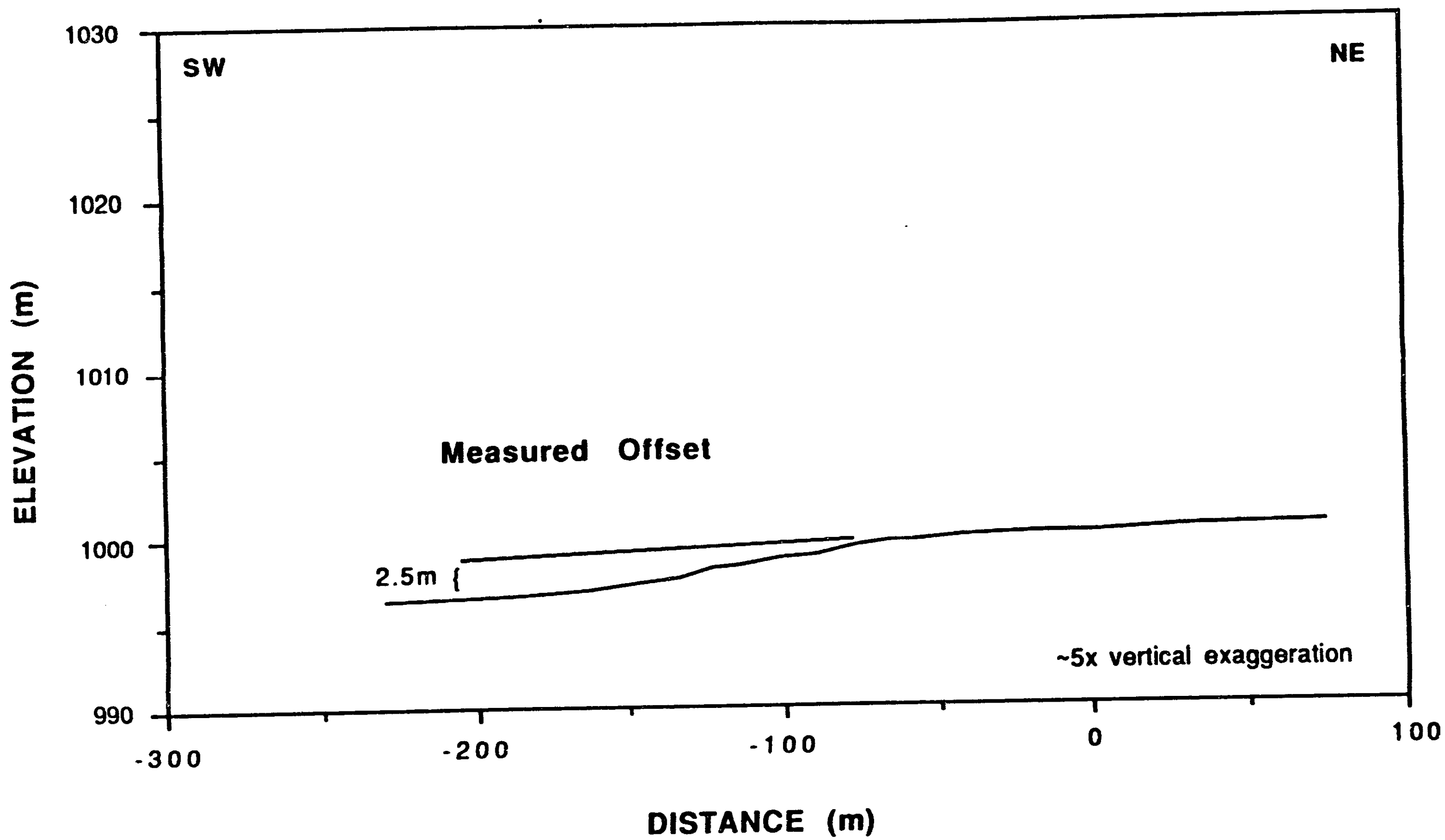


Figure 28. Scarp profile across a fault trace within the northern part of the Pahrump Valley fault zone. (Location 14, Plates 1 and 4).

The profiles were surveyed with a total station geodolite and oriented perpendicular to the fault trend. The faults are cut into the Qya unit of Malmberg (1967) or the old playa (op) unit of this report.

Most vegetation lineaments are defined by the presence of abundant phreatophytes (vegetation rooted in shallow groundwater) on the upthrown or upgradient, east side of faults, and sparse phreatophytes on the downthrown, west sides. These lineaments indicate that groundwater is impounded behind faults, and that the water table is locally elevated on the upthrown side. Evaporite deposits (Location 15, Plates 1 and 4; Figure 29) occur on the upthrown sides of faults where water seeps from the ground near the fault. Commonly water appears to seep from the scarp itself, hastening degradation of the scarp face.

Some vegetation lineaments are formed by a sharp line of phreatophytes. In these cases, either the fault acts as a conduit, bringing water nearer to the surface, or the fault is weak, allowing roots to penetrate to greater depths. The orientation and linearity of these vegetation lines suggest that they are of tectonic origins (Location 17, Plates 1 and 2; Figure 30).

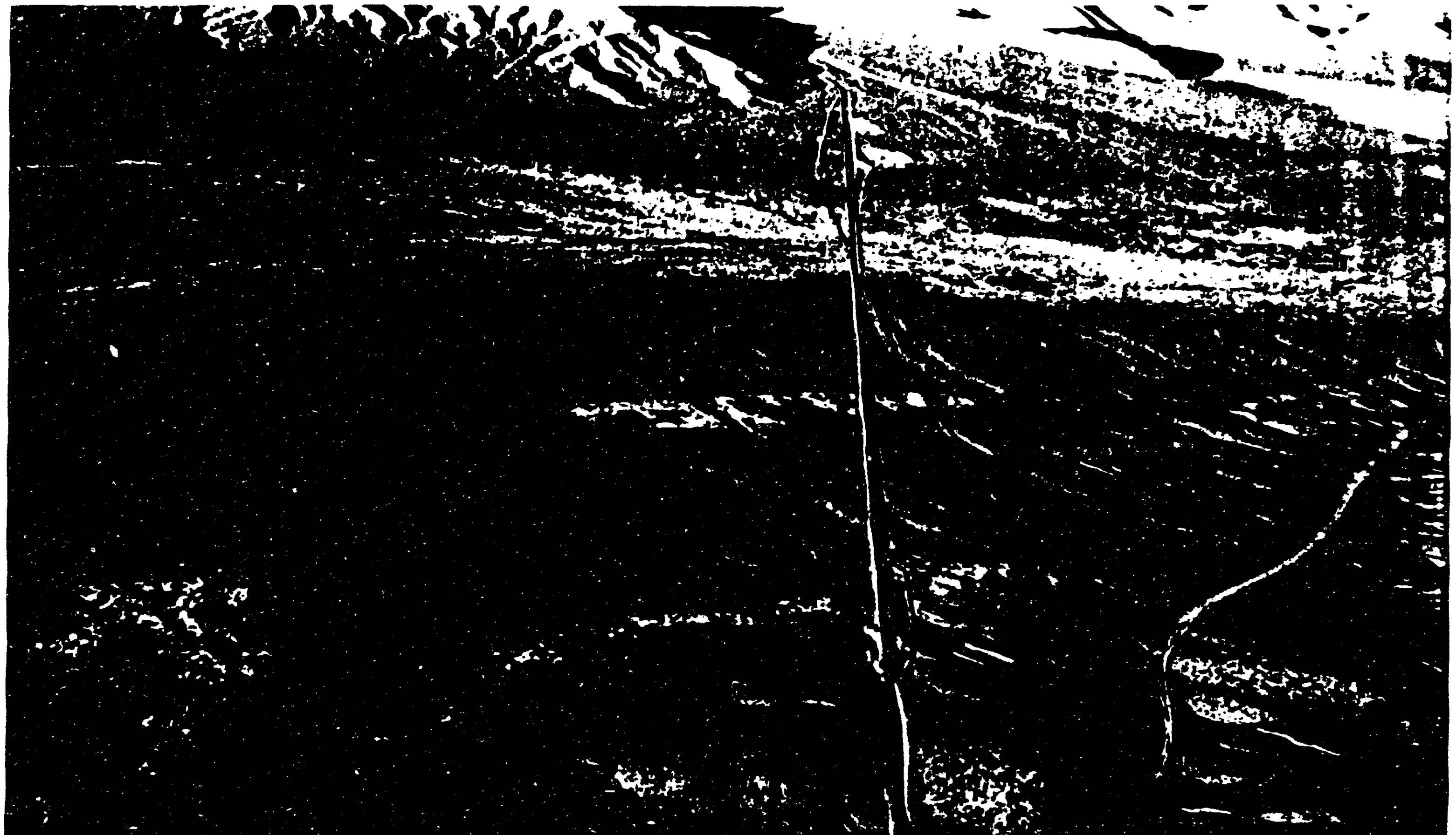


Figure 29. Evaporite deposits along young fault scarps within the Pahrump Valley fault zone. View is to the northwest, along California Highway 178. Stewart Valley road is at right. (Location 15, Plates 1 and 4).

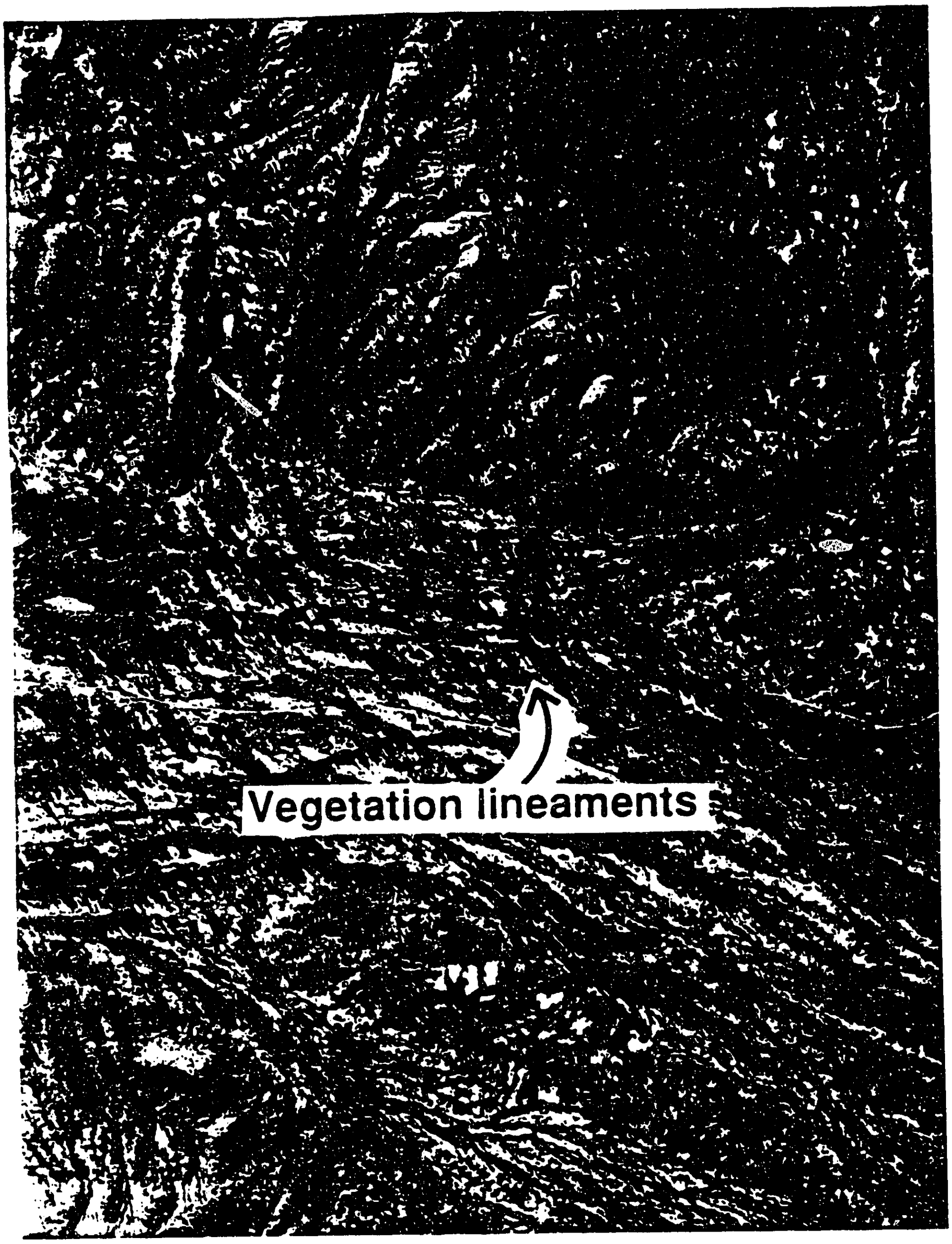


Figure 30. Low-sun-angle aerial photograph showing prominent vegetation lineaments that are interpreted as marking fault traces within the northern part of the Pahrump Valley fault zone. (Location 17, Plates 1 and 2).

Stewart Valley Faults

The young faults in the northern part of the PVFZ continue into southeastern Stewart Valley north of Highway 178 (Plate 1). Several young scarps that cut probable mid to upper Holocene(?) playa sediments in Stewart Valley indicate these faults are active. The sediments cut by the faults are estimated to be mid to late Holocene based on the facts that they were deposited within the same depocenter as the modern playa at an elevation less than 8 m above the modern playa, and show little erosion of the original depositional surface. These deposits are incised less than two meters by the modern drainages flowing into the Stewart Valley playa.

Figures 31 and 32 are scarp profiles across one fault scarp at Location 18 (Plates 1 and 5). A small berm, less than 30 m wide by 2 m high, has formed along the upthrown edge of the scarp. The origin of the berm is problematic. It may have resulted from minor compression across the fault, either from a compressional bend or step along a strike-slip fault or from the interaction of two nearby fault strands; however, the fault trends slightly northeast of the main fault trend, an orientation more appropriate for an extensional rather than a compressional bend along right-lateral fault zone. Furthermore, only one active fault trace is located near the berm. Perhaps a more plausible

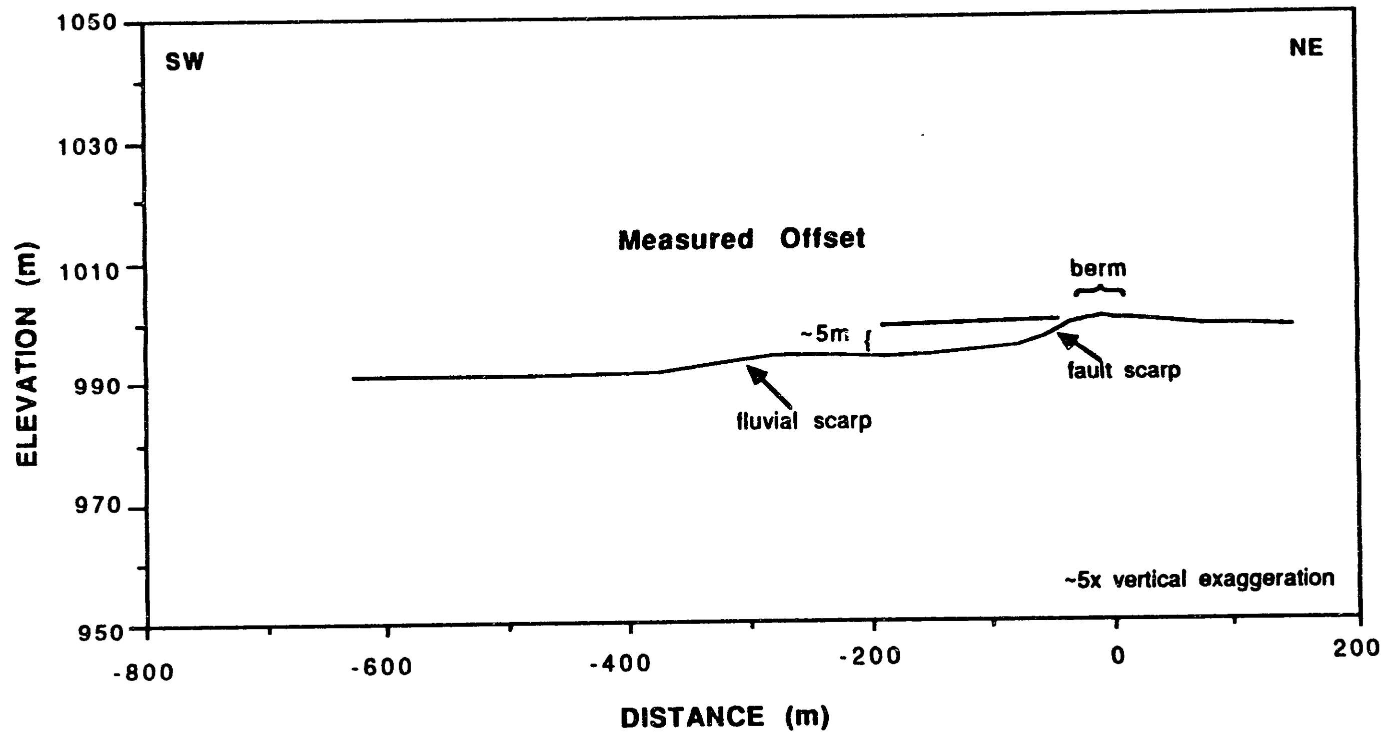


Figure 31. Scarp profile across a young fault splay along the northern part of the Pahrump Valley fault zone in Stewart Valley. (Location 18, Plates 1 and 5).

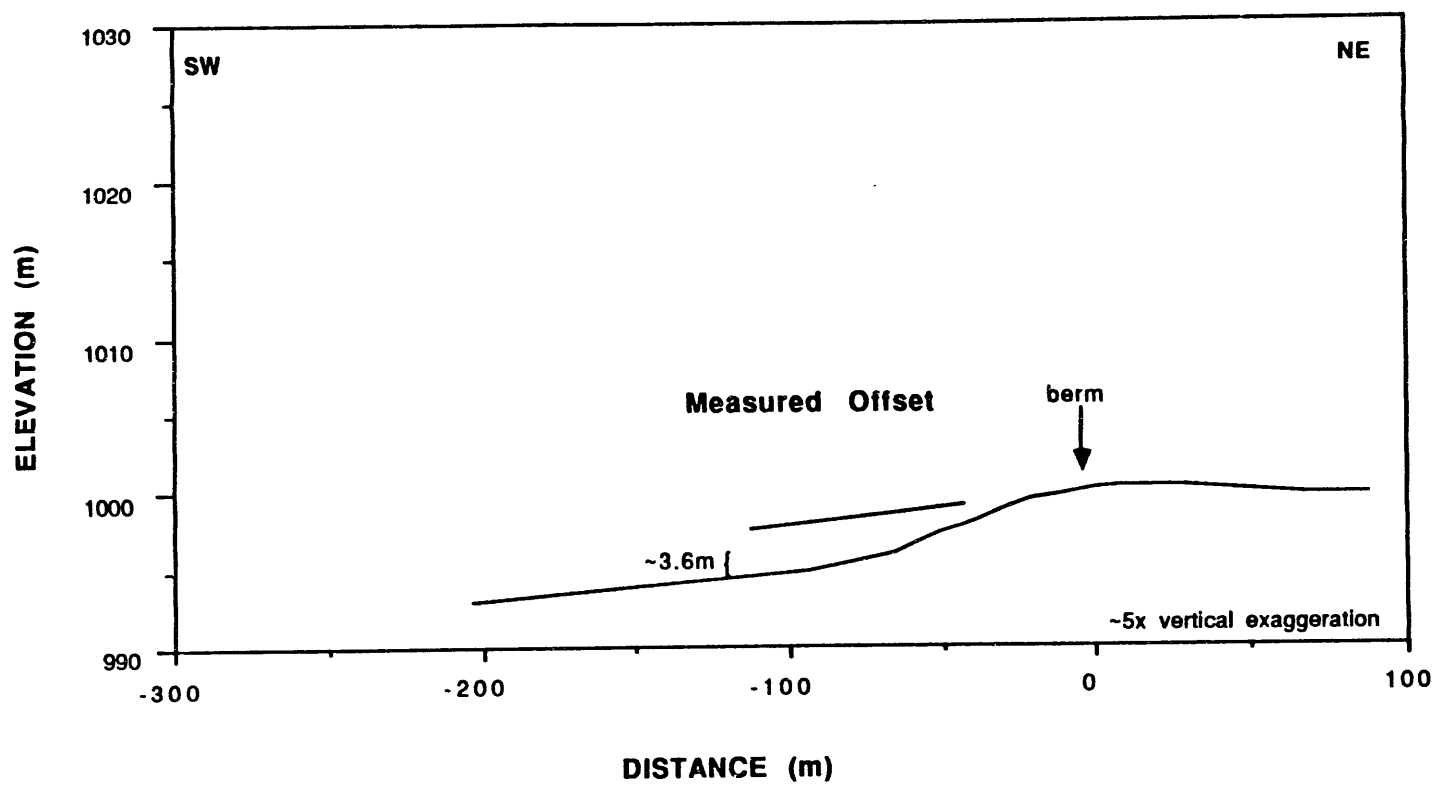


Figure 32. Scarp profile across a young fault splay along the northern part of the Pahrump Valley fault zone in Stewart Valley. (Location 18, Plates 1 and 5).

explanation is that the berm could have formed from the accumulation of eolian sediments fixed by increased vegetation on the wetter, upthrown side of the fault. Berm-shaped accumulations of sediment occur in several places around the playa rim, and are not always directly associated with faults.

At Location 19, Plates 1 and 5, a very young (late Holocene?) basin has formed. This basin is approximately 200 m x 50 m and is over 3 m deep. The basin could represent a small-scale, extensional pull-apart feature formed along north-trending faults, a basin opened along a right bend in a fault trace, a sag pond formed along an active fault trace, or a sink-hole caused by excessive groundwater withdrawal. Modern drainages are deflected around a low berm along the basin rim. The lack of erosion of the berm indicates that the berm is a young, probably late Holocene feature.

Along the northeastern side of Stewart Valley, a broad vegetation lineament (Figure 33) has a trend that coincides with the trends of the scarps in the southeast part of southern Stewart Valley, and is probably tectonically controlled. A low-relief and highly eroded scarp along the west edge of the vegetation lineament may be a fault scarp, a shoreline feature, or some combination of the two (Location 20, Plates 1 and 5). The alluvial fans along the west

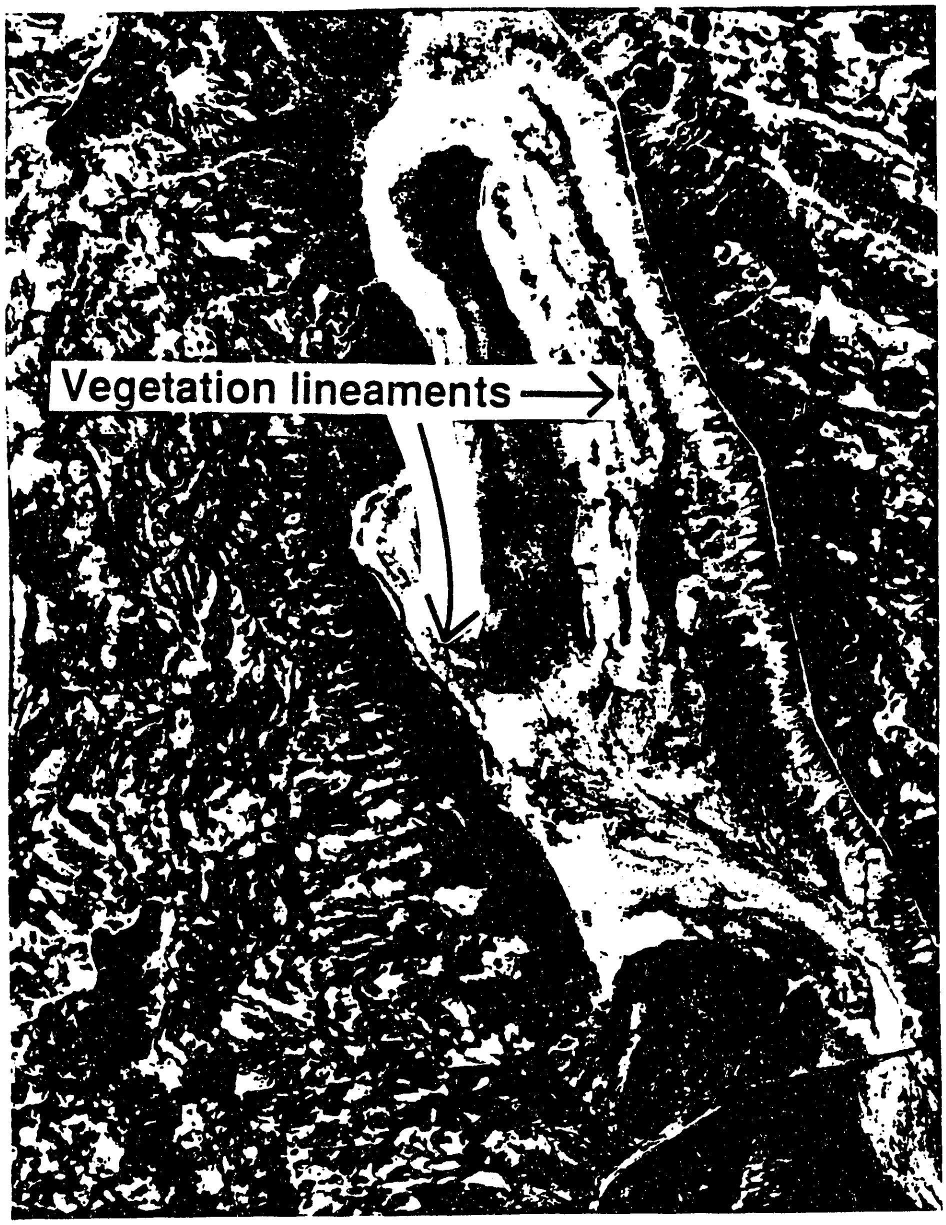


Figure 33. Vegetation lineaments along the west and east edges of the Stewart Valley playa. (Locations 2 and 20, Plates 1 and 5.)

flank of the Montgomery Mountains also show some minor vegetation lines (Location 21, Plates 1 and 5) that are interpreted to be fault traces crossing young alluvial fan surfaces (Qya unit of Malmberg, 1967).

Along the southwest margin of Stewart Valley playa, another strong vegetation lineament marks the playa/alluvial fan contact (Location 2, Plates 1 and 5). Although it may be a tectonic feature, no scarp is associated with this lineament. At the northwest end of Stewart Valley playa, a young alluvial fan built onto the playa is not cut by faults. Evidently, faults along the southwest side of Stewart Valley are not as young as those along the eastern side of Stewart Valley.

Fault Patterns

The PVFZ is over 50 km long and over 6 km wide. In the southern part of the fault zone, the PVFZ consists of two subparallel fault traces over 15 km long and several distributed small fault traces, the longest of which is over 6 km long. The two main traces are oriented N45°W with minor fault traces oriented from N45°W to N30°E, with an average orientation of N5°E. The two main traces are fairly continuous laterally over the southern part of the PVFZ. The smaller subsidiary faults are distributed mostly west of the two main traces. Many of these lineaments may or may not represent true faults at depth. The smaller faults most closely resemble a relay pattern (see Biddle and Christie-Blick, 1985) in that there is no systematic left or right steps to the fault segments. The smaller faults seem to step to the left or right in a random pattern. There is not much overlap in the fault segments. However, the fault segments appear to occur in zones where two or three short fault segments lie side by side, aligned along the main fault trace, and distributed over a width of up to 1.5 km. Orientations were measured for several of the smaller fault segments and plotted on a rose diagram (Figure 34). This diagram shows that many faults are oriented ~N25°W, at an angle of ~20° to the main fault trace. These may represent Riedel shears related to the main fault trace. A few of the minor fault segments are oriented up to N30°E, at an angle of about 75° E of the main fault trace. These may represent R' shears. Riedel or R shears generally form at an angle of $\phi/2$ (where ϕ represents the peak angle of shearing resistance) and R' shears generally form at an angle of $90 - \phi/2$. Therefore, the peak angle for shearing resistance of the Plio-Pleistocene(?) unit into which these faults are developed, may be on the order of 30 to 40°.

The two main fault traces die out south of the northern part of the PVFZ, south of latitude 36° 05' N. In the northern part of the PVFZ, north of latitude 36° 05' N and

Trends of minor faults and lineaments of the PVFZ

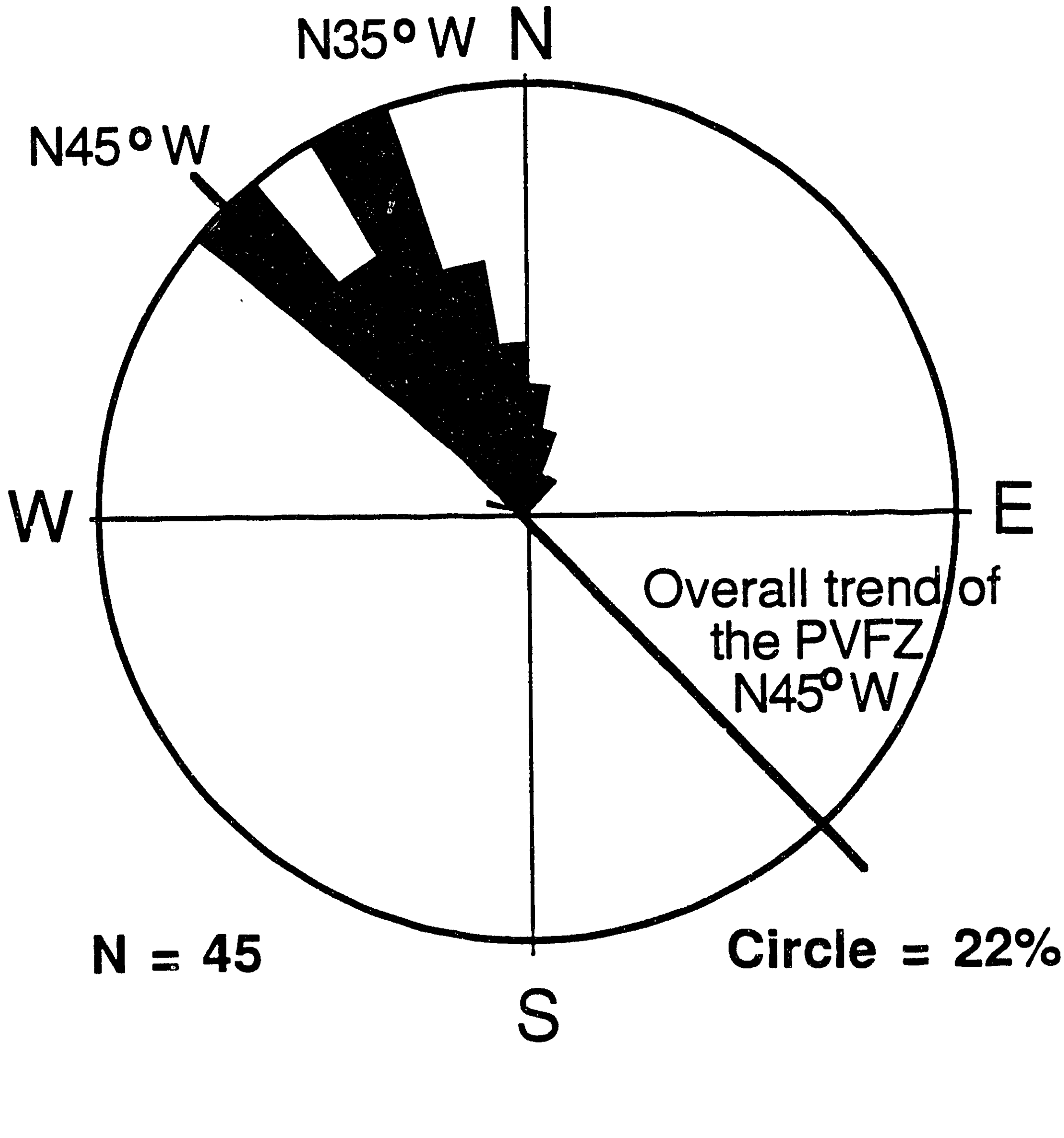


Figure 34. A rose diagram showing two dominant fault and lineament trends. One is aligned with the main PVFZ trend and the other may represent Riedel shears.

in Stewart Valley, the fault zone is a zone of widely distributed short fault segments. Most of these segments have scarps cut into fairly young alluvium (possible Quaternary(?) age 'YA' and 'OP' units on plates 2, 4, and 5). In general, these fault segments are subparallel to the main trend of the PVFZ. However, in Stewart Valley, most of the fault traces are oriented between N25°W and N30°W, 15 to 20° more northerly than the main fault zone alignment. Though these fault traces could be interpreted as Riedel shears, it seems more likely that the change in orientation results from structural control imposed by the southern end of the Montgomery Mountains. The N25°W to N30°W orientation of these fault segments mimics the orientation of the western flank of the Montgomery Mountains.

Several faint vegetation lineaments of possible non-tectonic origins in southeast Stewart Valley are oriented ~north. Two of these bound a small basin discussed earlier in this report. It is possible that this small basin between two more northerly oriented possible faults may result from a slightly more extensional component across the faults.

Interpretation of Displacements

The QTol unit of Malmberg (1967) is offset by up to 15 m along the main escarpment along the southern part of the PVFZ. Where clearly demonstrable surface offsets occur, the sense of displacement is consistently west-side-down. Several lineaments occur in this unit, west of the main escarpment. However, these lineaments do not have vertical surface offsets.

The sense of offset on the faults along the northern part of the PVFZ is consistently west-side-down. Scarp height is up to 5 m. No lateral offsets of stream channels or other geomorphic features were observed. Many of the faults have no clear surface offsets.

Faults of the PVFZ clearly have a west-side-down component of displacement. However, the linear trace of the fault, a relay pattern of the young faults of the northern part of the PVFZ, possible Riedel shears, and fault splays that step to the left are all consistent with a right-lateral component to the fault. Therefore, the PVFZ is interpreted as a right-oblique fault.

Recency of Activity

Along the PVFZ, the largest escarpment occurs on the southern part of the fault zone, from south of the map area near Stump Spring to a point just north of Browns Spring, where major north-trending fault splays intersect the main escarpment. In the southern part of the PVFZ, the youngest unit that is clearly offset by a fault is the unit mapped QT on Plates 1 and 3 and the unit mapped QTol by Malmberg (1967). However, as depicted in Figure 20, younger deposits that are inset into the QTol unit are also faulted. These faults are probably pre-Quaternary since there is no surficial expression of the fault and the fault does not cut the pediment surface built onto these younger deposits. The age of these deposits is not known.

The exact age of the most recent offset on the southern part of the PVFZ is unknown. The main escarpment in the erosion resistant QTol deposit of Malmberg (1967) has over 8 m of relief along most of its length. However, the escarpment itself is highly sinuous and dissected, and the pediment surface on both the upthrown and downthrown sides of the escarpment is also highly dissected. The eroded and sinuous trace of this escarpment indicates that there has not been major movement across this fault trace for quite some time. Observation of recent fault scarps may be complicated by the fact that resistant beds within the Plio-Pleistocene(?) deposits create a step-like appearance to the escarpment, which could mask the expression of youthful scarps. The pediment surface itself has been faulted down-to-the-west along the main escarpment. Although the deposits on which this pediment surface has formed are not precisely dated, it is possible that the pediment may be age-equivalent to the pediment surface mapped as the Ivanpah

Upland, estimated to be late Pliocene to Quaternary in age (Hewett, 1956). If so, the fault event(s) that created the main PVFZ escarpment could be Quaternary in age.

At the northernmost drainage near Browns Spring (Figure 19), deposits in an inset stream terrace have been radiocarbon dated at 880 +/- 50 yrs (J. Quade, pers. comm., 1989). This stream terrace is not faulted. This shows there has been no fault activity at the main escarpment near Browns Spring since 880 +/- 50 yrs.

In the Stump Springs area, 2 km south of the southern map boundary, mapping of upper Pleistocene to lower Holocene sediments shows that in one location, younger strata have been deposited against older strata in a buttress unconformity with a nearly vertical contact. This contact may be a buried fault scarp (J. Quade, pers. comm., 1989).

Sand dunes of probable Holocene age bury the escarpment along much of its length. These dunes do not appear to be faulted on the low-sun-angle aerial photography. However, it would be very difficult to perceive a fault offset on these dunes since they are easily eroded and highly vegetated. Though no faults are apparent across these dunes, the possibility that the dunes have been faulted cannot be precluded.

The alignment of cemented alluvial fan deposits and spring mounds along the westernmost trace of the fault zone shows little geomorphic indication of young fault activity, though subtle vegetation and tonal lineaments may indicate some minor fault activity.

Along the northern part of the PVFZ, numerous scarps cut the unit mapped as Qya by Malmberg (1967) or the 'op' unit on plates 2, 4 and 5. The age of these deposits is unknown in detail. These faults are inferred to be young, probably late Pleistocene in age, based on the geomorphically youthful appearance of the fault scarps, the straight, linear fault traces, and the distinctive appearance of the scarps on the aerial photography. The scarps are cut into old playa sediments. These deposits are mostly unconsolidated clays and silts, and because they are easily eroded, the youthful appearance of the scarps implies youthful faulting.

In Stewart Valley, the youngest unit cut by faults is probably of late Pleistocene to early Holocene age. Though the units cut by the faults are not dated, these probable young playa deposits are located within the same depocenter as the modern playa in Stewart Valley, and are shallowly dissected by the modern drainages into the Stewart Valley playa. These deposits are only a few meters in elevation higher than the elevation of the playa in Stewart Valley. Soils on these surfaces were not examined in detail, but cursory field examination showed a weakly developed Bt soil horizon. Since this soil is developed in fine-grained deposits, the presence of a weak Bt horizon may indicate a late Pleistocene to early Holocene soil.

The scarps developed along the PVFZ in southern Stewart Valley have a geomorphically youthful appearance. Although there is some degradation and dissection of the scarps, the scarps are linear and distinct on the air photos. None of the deposits or surfaces cut by the PVFZ have been dated precisely. In addition, no measurable lateral offsets of young geomorphic features have been observed.

I interpret the distributed nature of the faults in northern Pahrump Valley and southern Stewart Valley, and the absence of faults on some of the younger inset fans in southern Pahrump Valley to mean that slip rates are low. The fact that most geomorphically youthful scarps occur along the northern part of the PVFZ suggests that the most recent ruptures have occurred along the northern portion of the PVFZ.

Summary

Based on the map patterns of the fault zone, the PVFZ is interpreted to be a right oblique-slip fault with a down-to-west normal component. The fault zone as a whole is oriented approximately N45°W, similar to other right-lateral faults of the Walker Lane Belt such as the Furnace Creek fault zone which trends N45°W and is interpreted to be a primarily right-slip fault with a minor normal component (Brogan et al., 1988), and faults within the Fish Lake Valley fault zone that trend N40°W and show right-lateral displacement (Sawyer, 1989).

THE WEST SPRING MOUNTAINS FAULT ZONE

The West Spring Mountains fault zone (WSMFZ) is approximately 30 km in length and has a general orientation of about N12°W, though the fault zone is somewhat curved and orientations range from N10°E to N50°W (Plate 1). The WSMFZ trends north into the Grapevine fault (Figure 5), a bedrock fault mapped by Hamill (1966) and Burchfiel et al. (1983).

No low-sun-angle aerial photography was available for the WSMFZ, so the fault zone was mapped from 1:80,000 scale black and white U-2 aerial photography with only cursory field examination. The WSMFZ was added late in the thesis project and, combined with the lack of detailed photo coverage, this resulted in a much less detailed study of the fault zone than the ENFZ and the PVFZ. However, the WSMFZ has a strong geomorphic expression, and much of the fault zone is easily mapped from 1:80,000 scale photos.

Aerial Photography and Field Expression

The WSMFZ consists of a single fault trace at its southern end, and this main trace continues northerly to the vicinity of Grapevine Springs. Multiple minor faults occur to the west of the main trace at the northern end. Some of these form fault grabens. The geometry of the WSMFZ fault zone is irregular, and mimics the geometry of the Spring Mountains range front. A mineralized zone at the bedrock/alluvial fan contact along the northern Spring Mountains range front (Location 22, Plate 1) may be an older expression of the range front fault.

Fault Patterns

The pattern of faults along the WSMFZ is fairly simple. The southern part of the fault zone consists of one main trace that is laterally continuous for over 12 km. This fault trace can be divided into two segments, each about 6 km long, the southern segment trending ~N10°E and the northern segment trending ~north though the fault trace is highly curved. In Wheeler Wash, 5 km northeast of the graben shown at Location 23, the fault zone makes a bend greater than 90°. The fault trace is continuous for 6 km both north and south of this bend, and observations from aerial photography do not reveal any significant difference in the scarp height on either side of the bend. The geometry of this sharp bend argues against a significant lateral component to the fault, since it would be difficult to displace units laterally across such a sharp bend without invoking contractional or extensional features near the point of maximum inflection.

North of Wheeler Wash, at Location 24, Plate 1, the single discrete fault trace dies out and the WSMFZ becomes a 5 km wide zone of distributed short fault segments that are subparallel to the range front. This zone of distributed faults is about 10 km long. The faults generally show west-side-down displacements with the exception of a 0.5 m wide graben. North of this zone near Location 24, Plate 1, the WSMFZ is expressed as a discrete mineralized zone at the alluvial fan/bedrock contact. This may be part of the Grapevine fault discussed by Burchfiel et al. (1983).

Interpretation of Displacement

Faults within the WSMFZ show consistently west-side-down offsets, except where they bound extensional grabens. In several locations, offset geomorphic surfaces on both the upthrown and downthrown sides of the fault, can generally be matched across the fault. Scarp heights appear fairly uniform across any single surface despite major changes in strike of the fault. The trace of the fault is sinuous, and in some places sharp bends in the fault geometry preclude lateral movement on the fault. Though a few extensional grabens are observed, there are no corresponding contractional features. The fault zone consists of one fault trace along the southern part, and the fault geometry mimics the range front geometry. All evidence therefore suggests primarily west-side-down normal displacement for the WSMFZ.

Recency of Activity

The WSMFZ cuts the Qya (Quaternary young alluvium) unit of Malmberg (1967). The youngest geomorphic surface cut along the western Spring Mountains range front has morphologic characteristics that most closely resemble a surface estimated as approximately 120,000 years old by Sowers (1986) at Kyle Canyon on the eastern Spring Mountains range front. Similar morphologic characteristics include a light color due to whitish calcrete fragments in the desert pavement, and a well developed pedogenic calcrete lying within two meters of the surface. However, the surface cut by faults of the WSMFZ has rounded ballena topography, similar to Sower's (1986) surface 1, estimated at greater than 730,000 yrs based on paleomagnetism of pedogenic calcrete, so the surface may be older than 120,000 yrs. This surface has scarps estimated to be greater than 20 m high. Geomorphic surfaces interpreted to be older based on their location higher on the fan surface, inset relationships, deeper drainages, and better formed and larger ballenas, have higher scarps. A scarp profile across a major graben at the southern end of the WSMFZ (Location 23, Plate 1; Figure 35) shows a minimum of 12 m of offset (Figure 36).

The younger surfaces at the base of the fan are inset into probable Holocene paludal deposits (J. Quade, pers. comm., 1989) and show no signs of faulting on the 1:80,000 scale aerial photography. Though the fault scarps along the WSMFZ are large, the scarps are highly dissected. A 200,000 year estimate for the age of the surface containing the large graben produces an estimated average vertical slip rate of 0.06 mm/yr. A reasonable range of 50,000 to 500,000 years for the surface age produces an estimated range of vertical slip rates of 0.2 to 0.02 mm/yr. Thus, rates of activity along the WSMFZ are also low.

Summary

The WSMFZ is interpreted to be primarily a dip-slip fault based on the facts that: 1) it has single, curved fault trace that mimics the range front geometry for most of its length, 2) extensional grabens have formed along the fault trace, 3) large scarps show primarily west-side-down displacements, 4) the WSMFZ probably correlates with the dip-slip Grapevine fault, 5) the more northerly trend of the WSMFZ is similar to other normal faults in the southern Great Basin such as the southern Death Valley fault zone

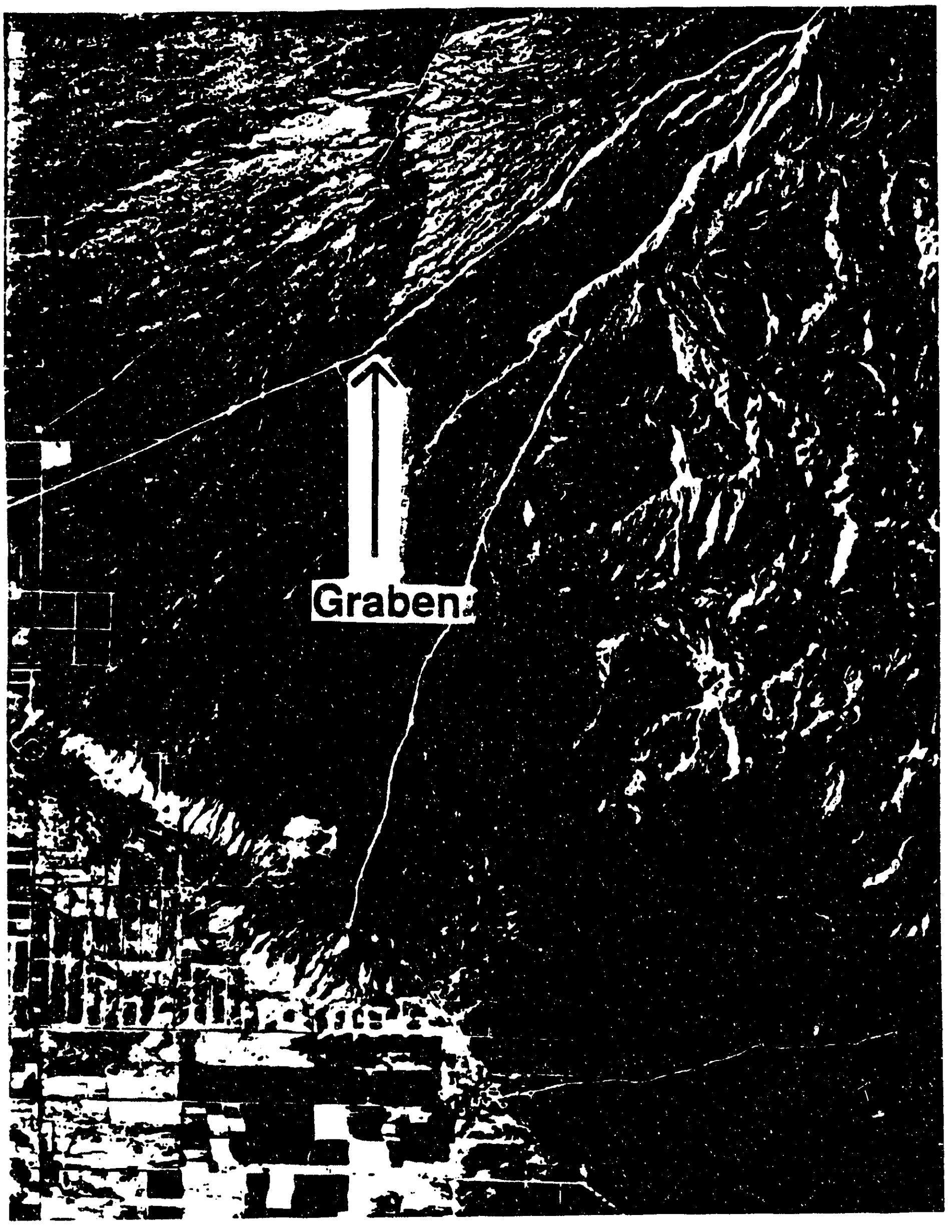


Figure 35. Black and white, 1:80,000 scale U-2 photograph showing a graben formed in young alluvial fan gravels along the West Spring Mountains fault zone (Location 23, Plate 1).

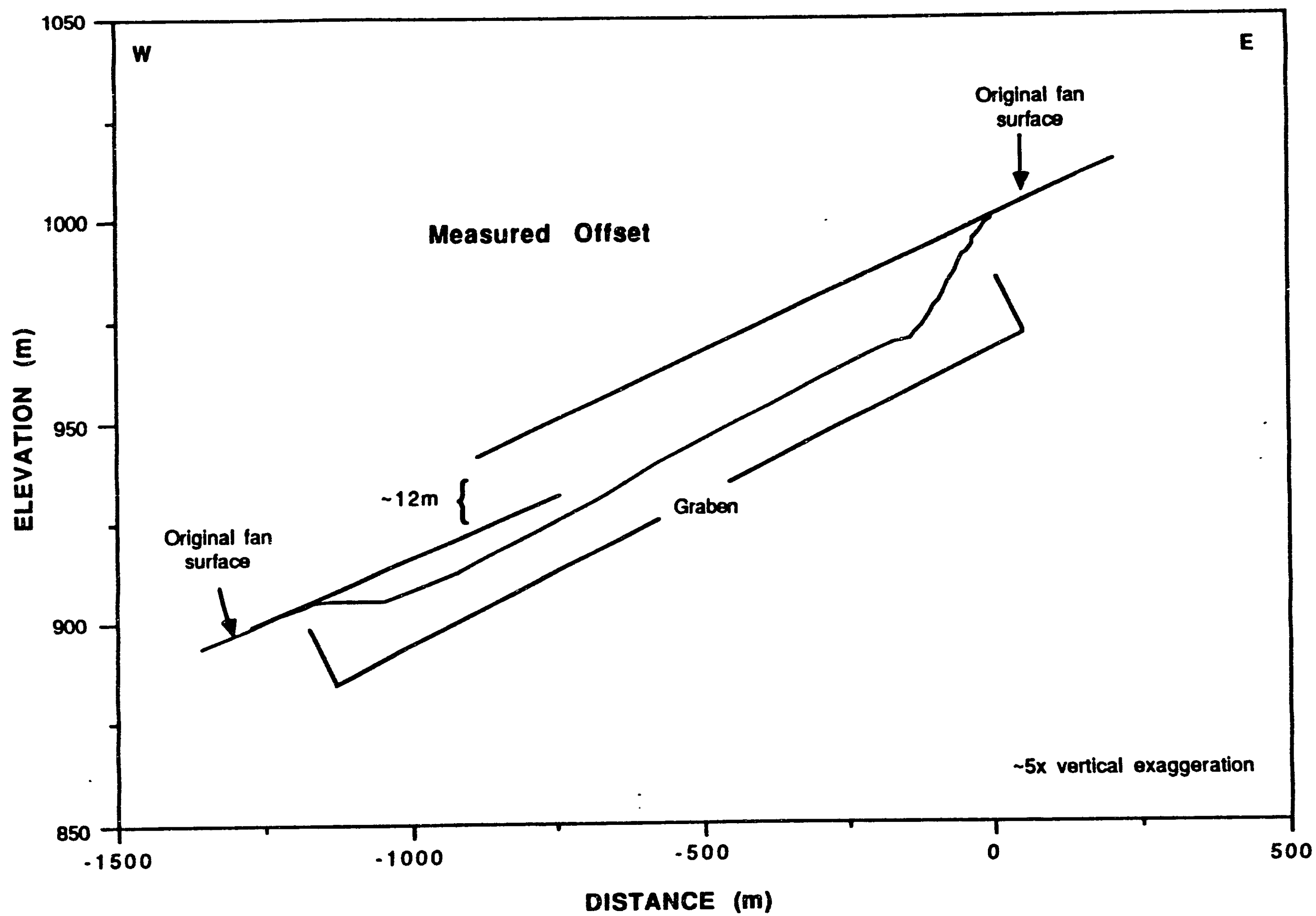


Figure 36. Scarp profile across the graben shown in Figure 35.

(Figure 7) and the normal-oblique segments of the Fish Lake Valley fault zone (Sawyer, 1989; Figure 7).

OTHER FAULTS AND LINEAMENTS OF THE PAHRUMP FAULT SYSTEM

Several faults and lineaments in Pahrump Valley are not easily grouped into the three major fault zones discussed above. For example, the boundary between the west edge of the Pahrump playa and Nopah Range alluvial fans is very linear but has no associated scarps (Location 25, Plates 1 and 2). This feature lies roughly midway between the ENFZ and the PVFZ. Although suggestive, I can provide no evidence that this feature is tectonic.

At the northern edge of the Pahrump playa (Location 10, Plates 1 and 2), several short lineaments in upper Holocene(?) playa sediments are oriented approximate N14^{o}E, and step to the left in en echelon fashion. No scarp is associated with these features. Several vegetation lineaments bordering the east side of the Pahrump playa (Location 26, Plates 1 and 3 for example) are subparallel to the PVFZ, and are probably of tectonic origins.

Vegetation lineaments at the south and southeast edge of Pahrump playa are of two different origins. A system of polygonal desiccation cracks have formed around the southern edge of the playa (Location 27, Plates 1 and 3). At the southeast edge of the playa, diffuse vegetation lineaments that are subparallel to the playa edge and that have no associated topographic relief may result from down-slope migration of saturated fine-grained sediments (Location 28, Plates 1 and 3). These 'lurch' features are commonly associated with seismic shaking (B. Robison, pers. comm., 1990). An alternative explanation for these features is that they represent vegetation rooted in buried desiccation cracks. Although the features are not as distinct and do not show the polygonal patterns of the modern desiccation cracks, in some places the modern desiccation features seem to pass gradually into these diffuse vegetation lineaments. Also, some fault lineaments project into these vegetation lineaments, and buried faults may control their locations.

Several major fault breaks have orientations intermediate between the PVFZ and the WSMFZ. These are major splays off of the main trace of the PVFZ (Figures 37 and 38). Many of these splays uplift the Plio-Pleistocene basin fill deposits that are exposed along the main PVFZ escarpment. Some of the splays exhibit as much as 12 m of apparent normal displacement (Location 31, Plates 1 and 3). The splays step to the left in en echelon fashion, suggesting that there may be a right-lateral component on the faults between the PVFZ and WSMFZ. In some places, (Location 30, Plates 1 and 3; Figure 38) the faults cut paludal(?) sediments of probable latest Pleistocene to Holocene age.

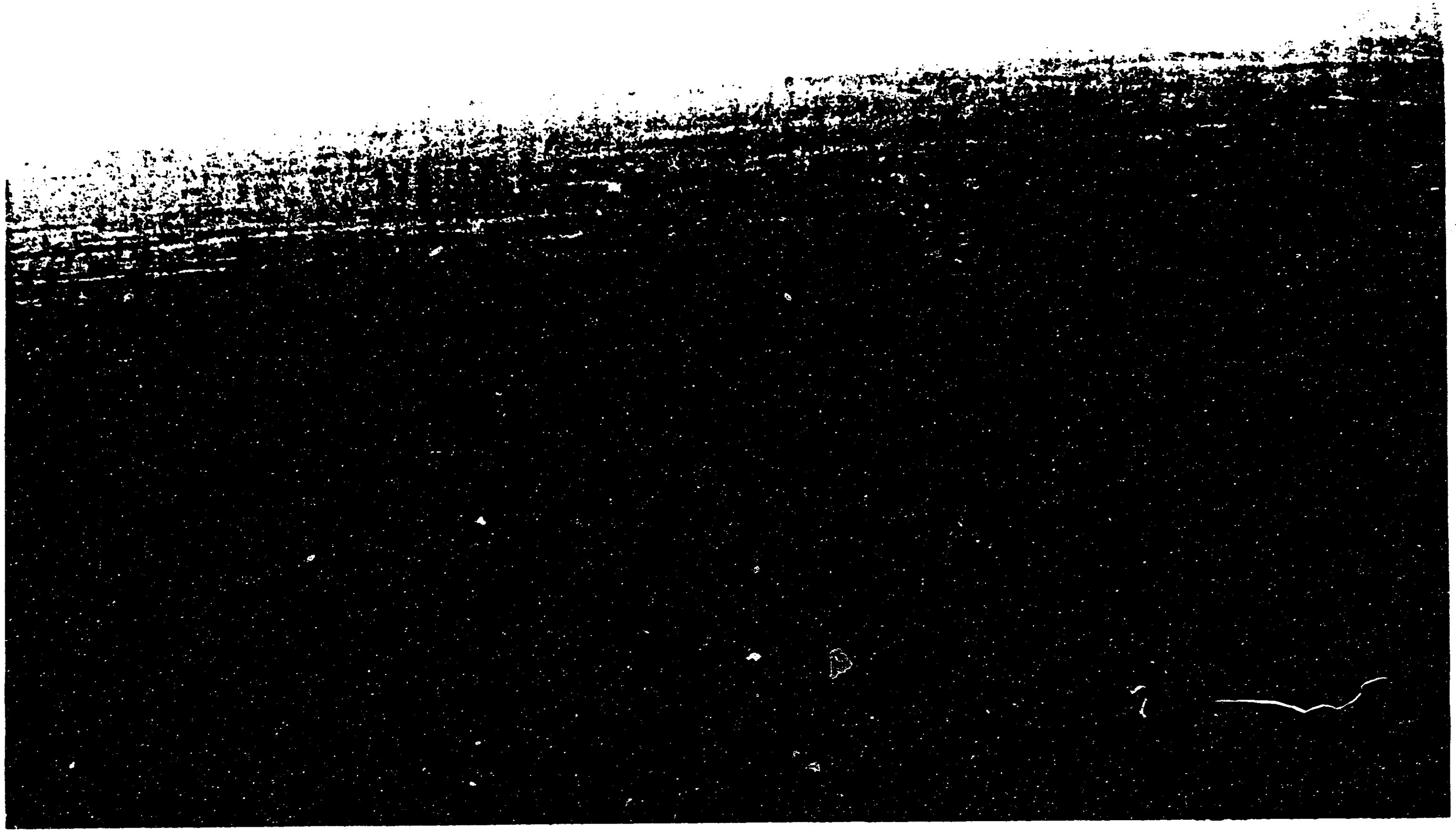


Figure 37. Fault scarps on young alluvial fans in the transitional zone between the Pahrump Valley fault zone and the West Spring Mountains fault zone. (Location 29, Plate 1).

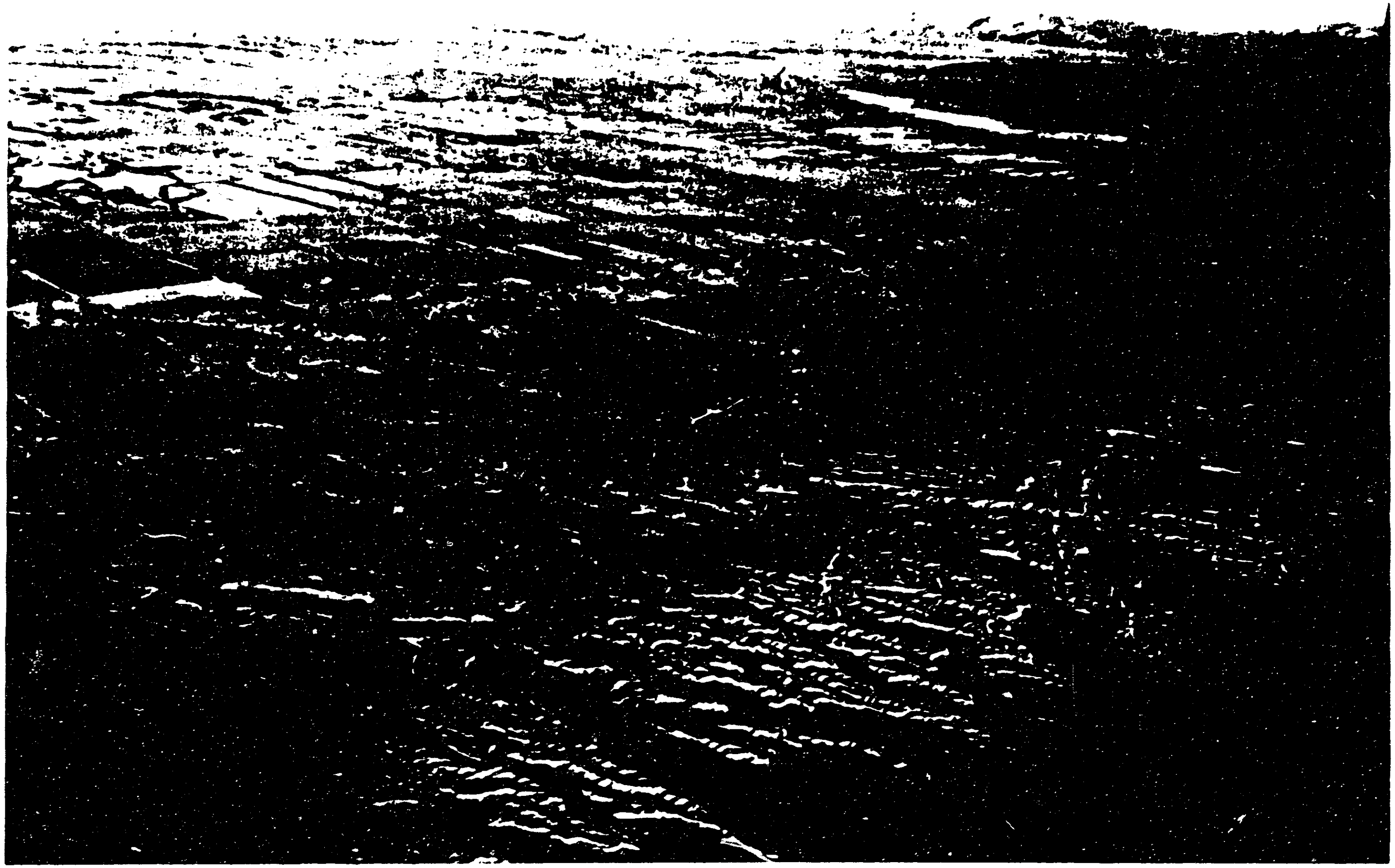


Figure 38. Faults cutting possible upper Pleistocene sediments in the transition zone between the Pahrump Valley fault zone and the West Spring Mountains fault zone. (Location 30, Plates 1 and 3).

Faulted alluvial fan remnants upslope of these scarps have unfaulted younger inset alluvial fan aprons that are also inset into the late Pleistocene to Holocene paludal(?) deposits. The fault scarps on the alluvial fan remnants have steep faces and appear young. Some of the splays trend directly north toward the WSMFZ, and are likely transitional faults between the PVFZ and WSMFZ.

RECENT FAULT PATTERNS

My interpretation of the patterns of active faults in Pahrump and Stewart valleys is that they collectively form parts of a northwest-trending dextral shear zone. The ENFZ trends N33°W and is a right-lateral strike-slip fault. The PVFZ trends N45°W and is a dominantly right-lateral strike-slip fault with a down-to-the-west normal component. The WSMFZ has a general trend of N12°W and is primarily a down-to-the-west normal fault. Intermediate structures include a set of en echelon vegetation lineaments in northern Pahrump Valley (Location 10, Plates 1 and 2) that trend north, and a zone of splays off of the main PVFZ that trends approximately N10°W (for example, Locations 31 and 32, Plates 1 and 3) showing down-to-the west offset with a possible component of right-lateral slip, as suggested by their left-stepping en echelon pattern. These patterns are consistent with deformation in a divergent dextral shear zone oriented N45°W, with a direction of maximum extension oriented approximately east-west (Figure 39).

SUMMARY OF THE PFS

The late Quaternary Pahrump fault system consists of three discrete fault zones connected by discontinuous faults that lie intermediate between the zones. The ENFZ and the WSMFZ both exhibit relatively continuous late Quaternary fault traces. The PVFZ has two continuous, but highly eroded late Tertiary to Quaternary traces at the southern end, and a broad zone of discontinuous late Quaternary faults at the northern end. Each of the three fault zones may correspond to a discrete fault at depth, or alternatively, they may be the surface expression of a broad dextral shear zone at depth, and may represent spatial partitioning of shear into strike-slip and normal components. The patterns of late Quaternary faulting alone cannot resolve which is the actual case. The discontinuous and distributed nature of the PFS precludes a realistic estimate of earthquake magnitudes based on fault lengths, and makes segmentation of the faults a difficult exercise.

If the faults of the PFS are parts of a broad shear zone at depth, the slip rates may be additive, and the fault system as a whole may have a somewhat higher slip rate than the slip rates of each of the individual fault zones.

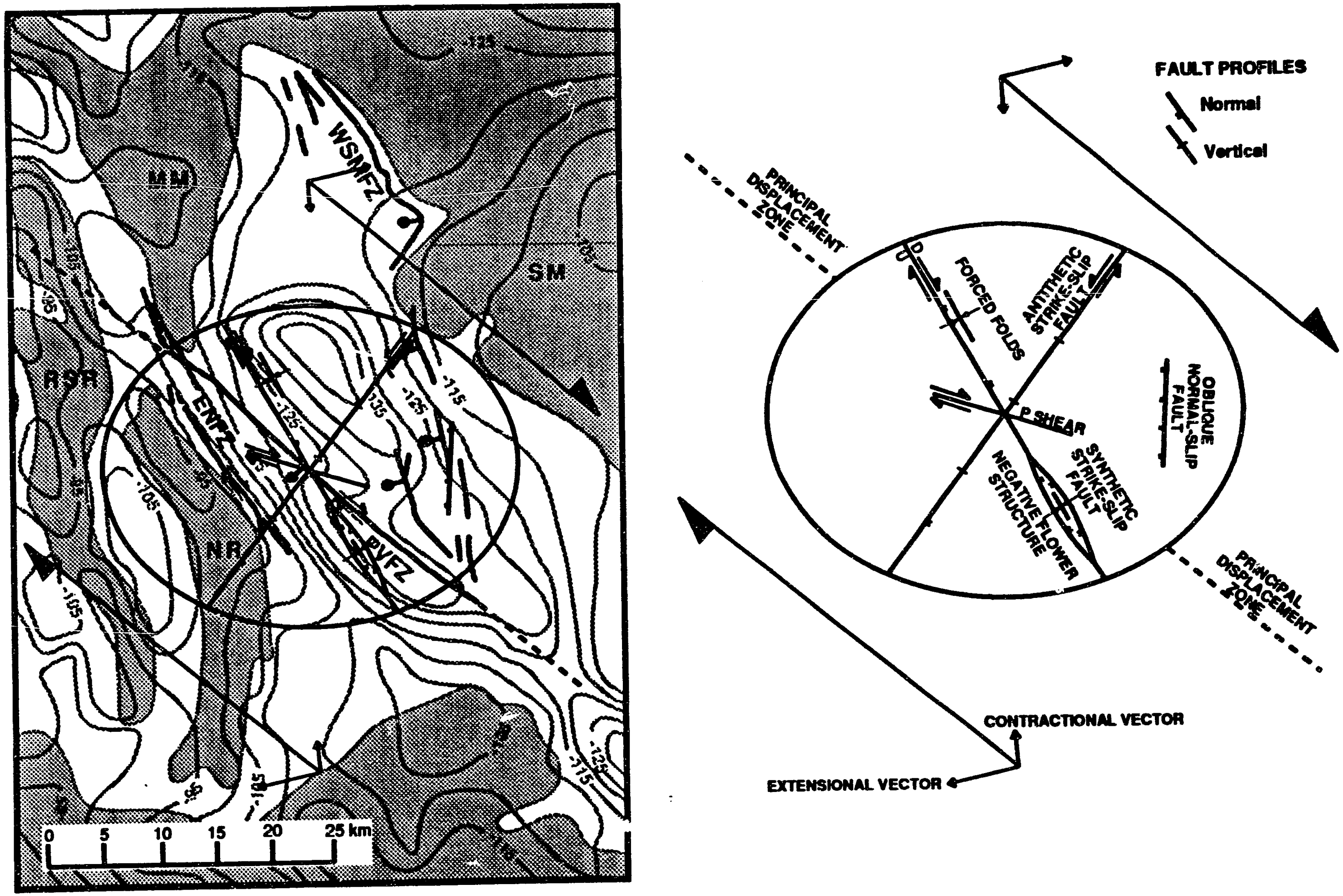


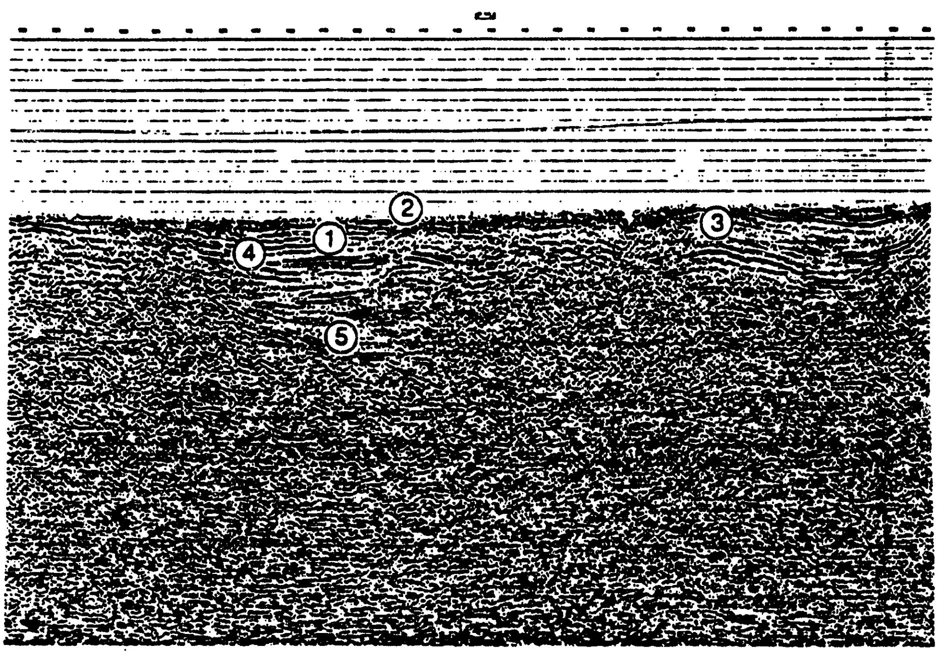
Figure 39. Idealized strain ellipse showing the predicted orientations of major structures in a divergent wrench-fault system (from Biddle and Christie-Blick, 1985).

SEISMIC EVIDENCE OF BASIN GEOMETRY

Seismic reflection profiles provide a subsurface view of the basin and fault geometries. Data collected from the profiles includes approximate dips on faults, distribution of faults, tilting or folding of basin reflectors and depth to the basin floors (Figure 40). This information is useful in determining the timing and style of displacements across the major faults, the longevity and style of basin formation, and the distribution of the basins.

Unpublished seismic reflection profiles for Pahrump and Mesquite Valleys were generously made available by Seismic Information Services, Inc., 16800 Imperial Valley Drive, Suite 400, Houston, Texas, 77060. These lines were shot in March, 1980, with a Primacord explosive source and were recorded with a Sercell 338 HR seismograph. Shot spacing was 220 feet and there were 48 groupings per shot.

These sections were originally produced for oil-exploration, and the velocity and migration models used in processing are unknown. Data from the uppermost one second of the sections were not supplied. If a velocity of 2.5 km/s is assumed for the missing interval (a reasonable value for unconsolidated sediments) slightly over one kilometer of section is not represented. If the basin fill has an average velocity of 4 km/s, there is little or no vertical exaggeration. At a velocity of 2 km/s, the vertical



1. Strong reflectors
2. Antiformal reflectors may represent diffractions off of faulted bedding
3. Folded reflectors
4. Truncated reflectors may represent a fault
5. Boundary of region of strong reflectors interpreted as basin floor

Figure 40. Features used to interpret the seismic sections.

exaggeration would be 2:1. My interpretations assume that vertical exaggeration is minimal.

I analyzed four of the seismic sections for this study. The seismic lines are roughly perpendicular to the PVFZ. Three of the lines cross Pahrump Valley and one crosses Mesquite Valley (Figure 41).

SEISMIC SECTION SSN-19

The northernmost line, seismic section SSN-19, runs through Chicago Pass at the south end of Stewart Valley and across northern Pahrump Valley (Figure 41). On this section, nearly flat-lying reflectors in northern Pahrump Valley appear to be disrupted by several high-angle faults (Figure 42). Using a velocity range (V_p) of 2.0 to 4.0 km/s the basin here is calculated to be 1.9 to 3.8 km deep. The basin is bordered on the east by a steeply west-dipping structure which may project to the surface at the WSMFZ. South of Stewart Valley, reflectors representing basin fill are folded into a broad, open synformal fold. East-dipping reflectors on the west side of this fold may represent the buried extension of the graben bounding fault along the west side of Stewart Valley. A west-dipping structure at the far west side of the seismic section may be a west-dipping fault passing under the Resting Spring Range.

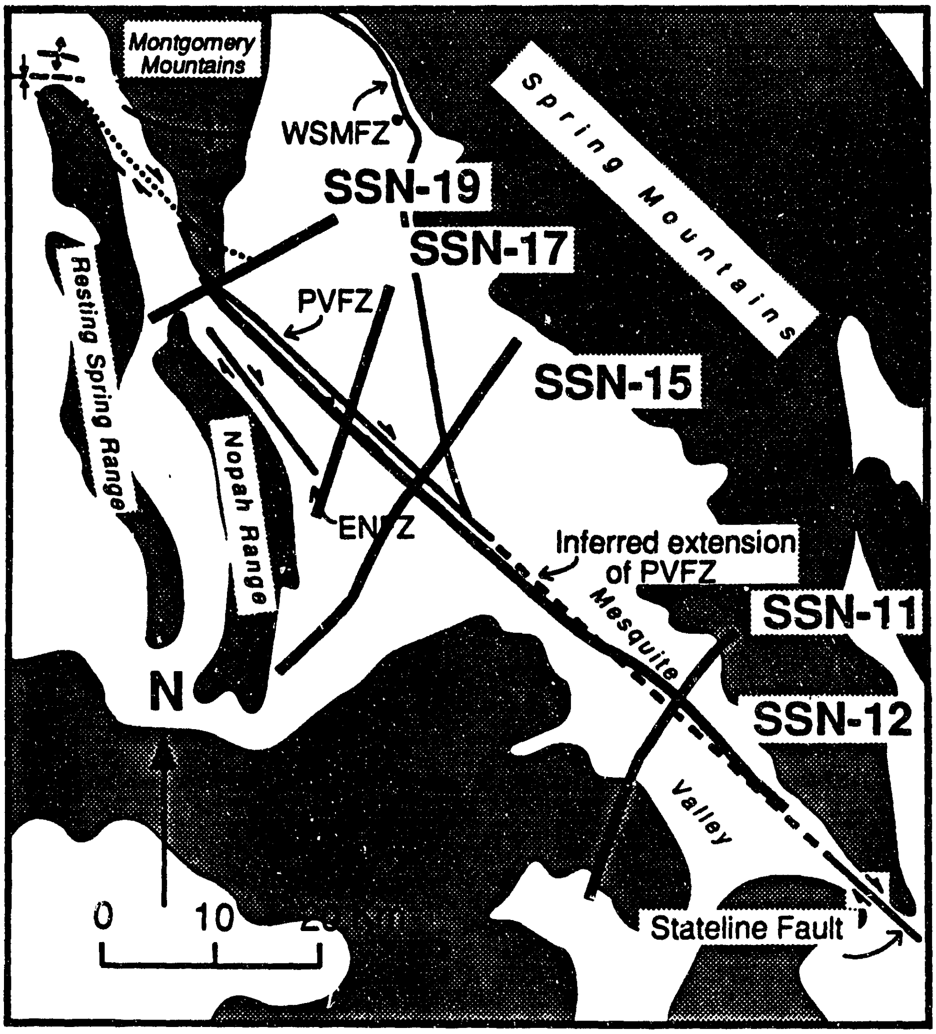


Figure 41. Location of seismic lines discussed in text.

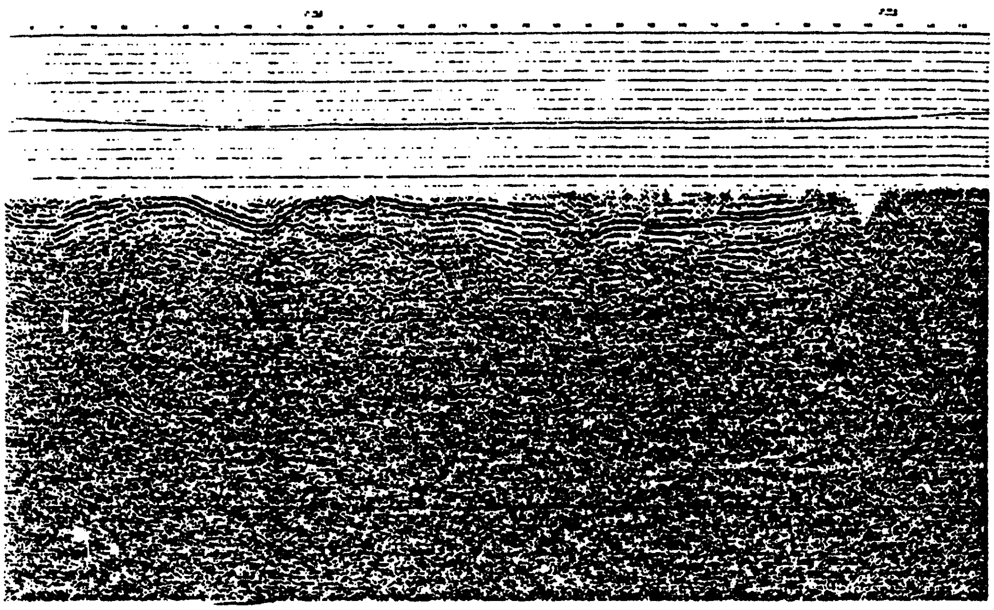


Figure 42a. Seismic section SSN-19. (The overlay for this section, Figure 42b, is located in the back pocket).

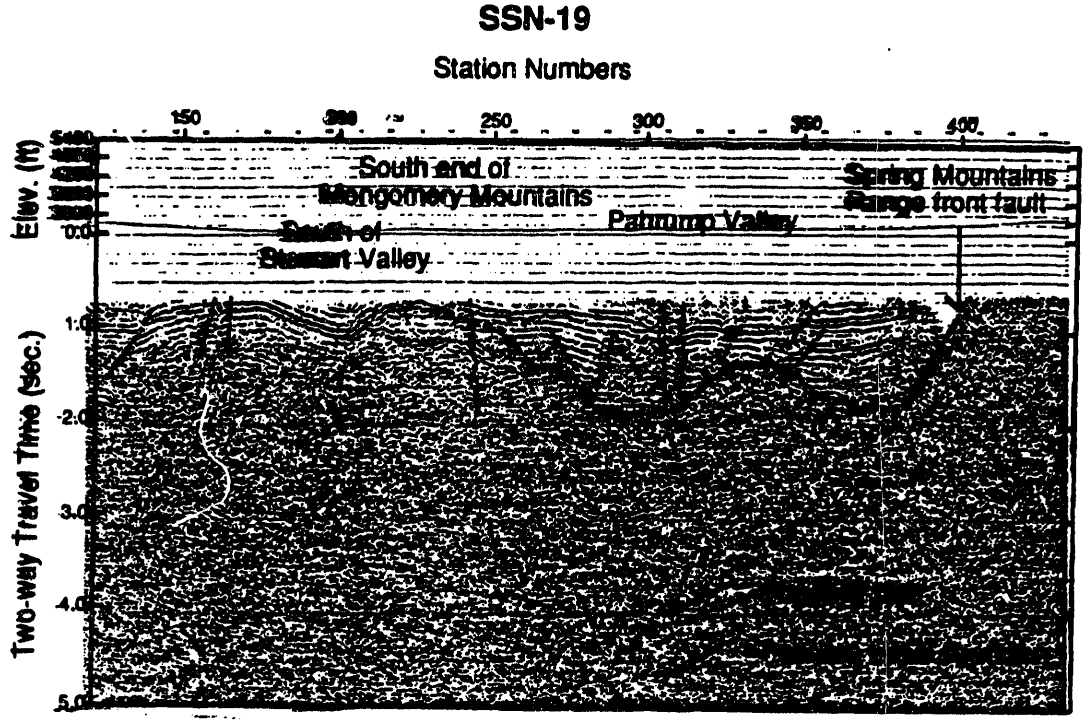


Figure 42b. Overlay showing interpretation of SSN-19.

SEISMIC SECTION SSN-17

Seismic section SSN-17 trends approximately N10°E and crosses the southwest part of Pahrump Valley (Figure 41). Calculations based on data from this section yielded estimated depths of 3.2 and 3.7 km for the two possible basin floors when using an estimated velocity (V_p) of 2.0 km/s , or 6.4 and 7.4 km depth when using an estimated velocity of 4.0 km/s (Figure 43). The deepest part of the basin is located in northeast Pahrump Valley. The basin is bounded on the east by a steeply west to southwest-dipping structure that probably coincides with the WSMFZ (Figure 43). Reflectors in the basin fill have an apparent shallow (<30°) dip to the north-northeast, and appear to be relatively uninterrupted by major faults or folds. Deep reflectors are evenly spaced, and show uniform dips indicating no syndepositional tilting occurred in the deeper part of the basin. A second group of shallower reflectors may represent a separate depositional episode. These reflectors have dips that increase with depth, indicating that syndepositional eastward-tilting of the basin occurred along a down-to-the-west normal fault at the eastern basin edge (Figure 43). This strongly supports the normal fault geometry previously inferred for the WSMFZ. In the central part of the seismic section, a horst-like feature lies just west of the mapped trace of the PVFZ. This structure appears to be bounded by

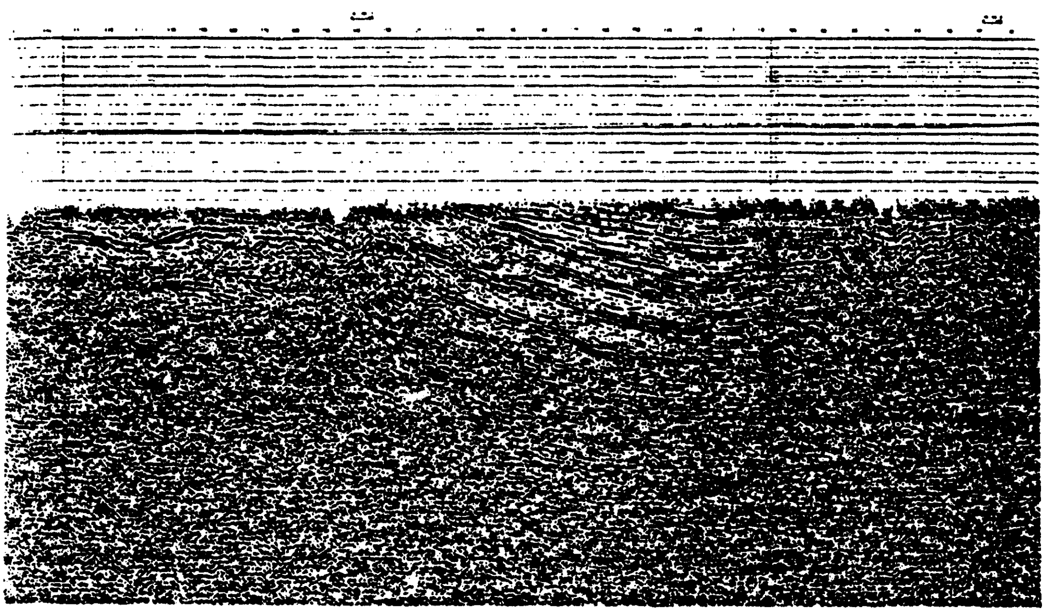


Figure 43a. Seismic section SSN-17. The overlay for this section, Figure 43b, is located in the back pocket.

SSN-17

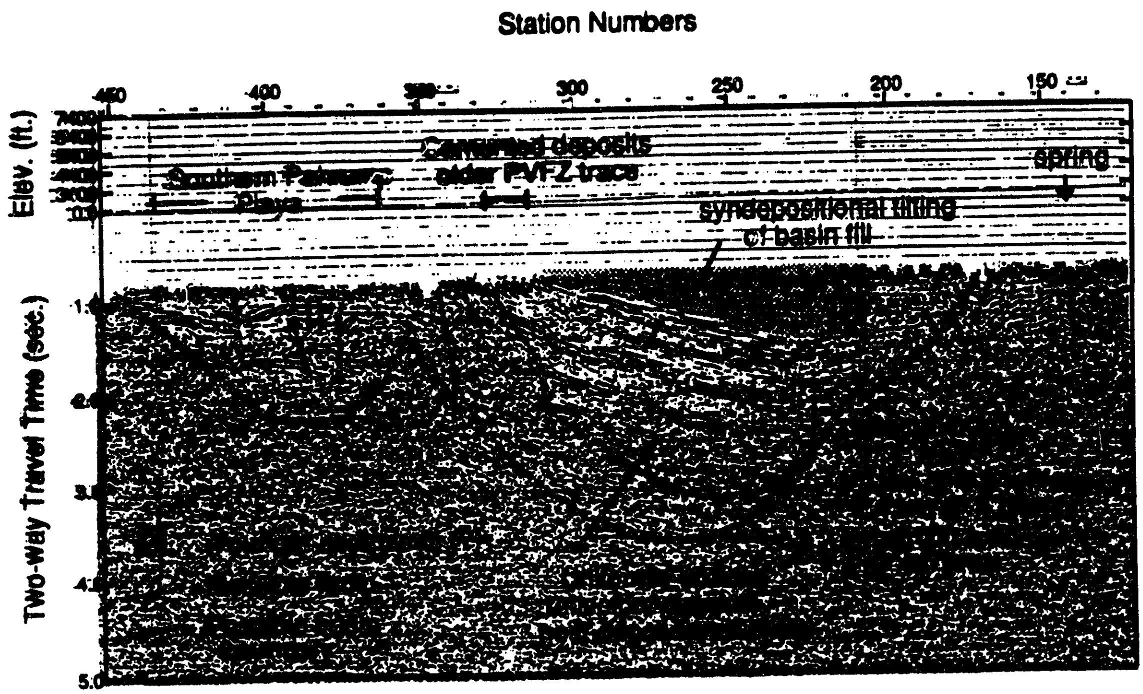


Figure 43b. Overlay showing interpretation of SSN-17.

steeply-dipping faults on the east and west. However, the east dips of reflectors with the eastern basin, and the lateral continuity and broad folding of reflectors in the western basin indicate that this feature is not a normal fault-bound horst, but a broad zone of shear disrupting a once continuous basin. Some of the disruption may also be due to folding. The west side of the basin is bounded by a moderately-dipping basin edge which may or may not be structurally controlled.

SEISMIC SECTION SSN-15

Seismic section SSN-15 crosses the south end of Pahrump Valley and trends about N45°E (Figure 41). This section also shows two basins separated by an apparent horst, which coincides with the position of the PVFZ (Figure 44). Both basins are ~2 to 4.5 km deep and reflectors appear to be disrupted by high-angle faults and deformed by broad folds. The folding and faulting is greatest in the deeper basin reflectors; shallower reflectors are less disrupted. West of the horst, the basin beneath the southern end of Pahrump playa is the same depth as its expression to the north, and east-dipping to flat lying reflectors within the basin are highly disrupted. This basin is bounded by high angle faults.

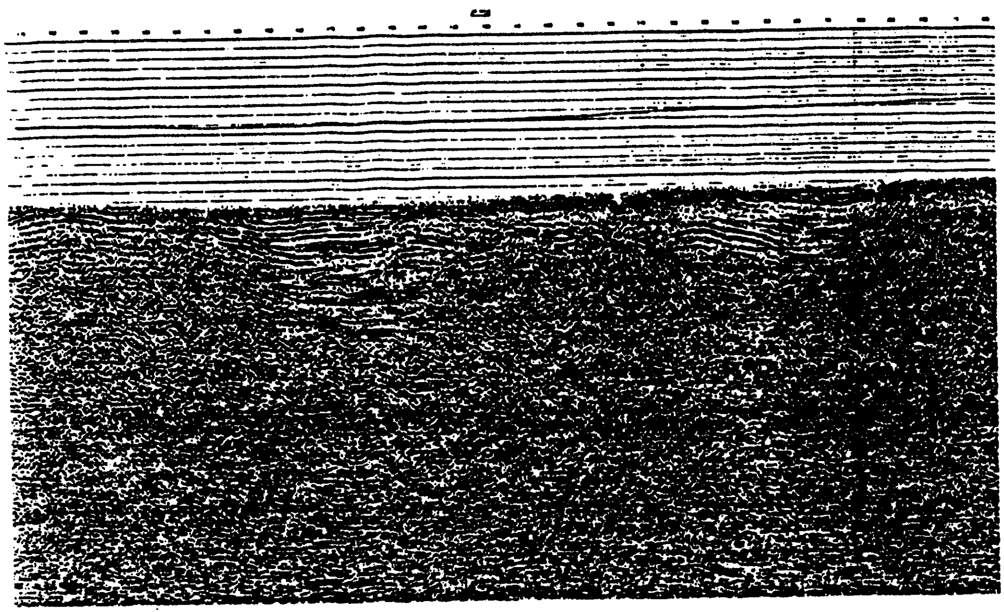


Figure 44a. Seismic section SSN-15. The overlay for this section, Figure 44b, is located in the back pocket.

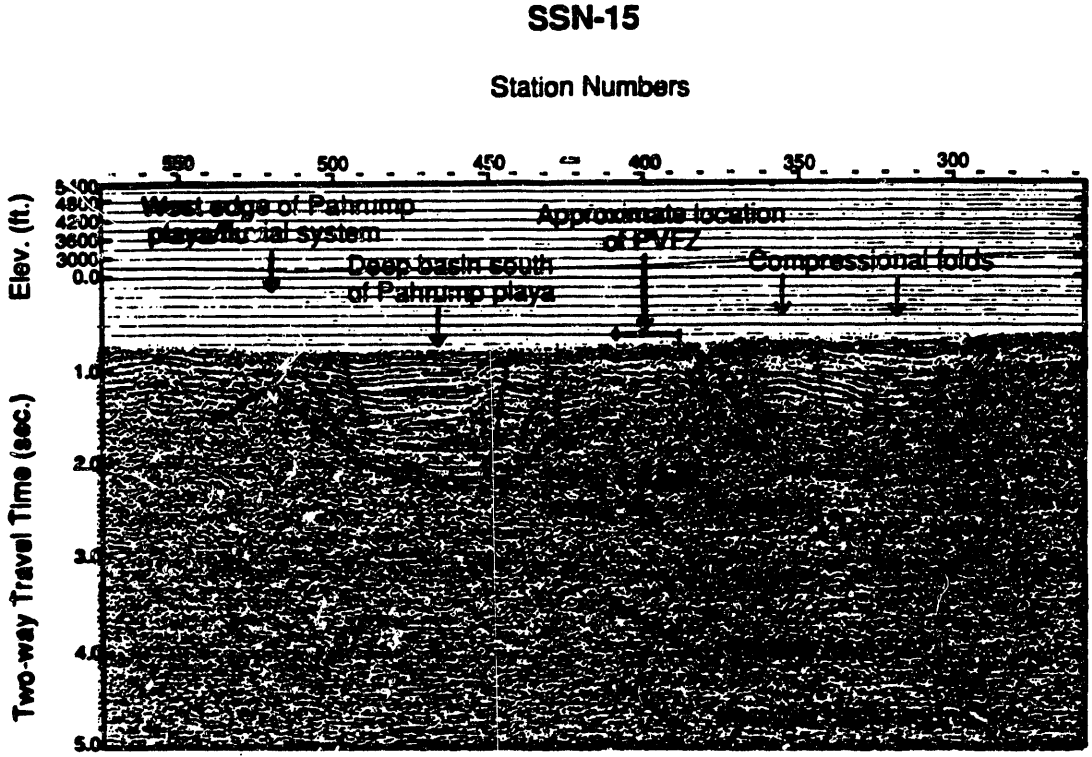


Figure 44b. Overlay showing interpretation of SSN-15.

SEISMIC SECTION SSN-11

Seismic section SSN-11 crosses central Mesquite Valley, some 30 km southeast of section SSN-15 (Figure 41). A basin with subhorizontal reflectors occurs in Mesquite Valley. The east side of this basin is bordered by a nearly vertical fault that coincides with the projected trace of the PVFZ (Figure 45). The western edge of the basin dips moderately eastward and may not be fault controlled. The basin reflectors are very diffuse in the deepest part of the basin but are much sharper in the shallower part and seem to reflect two separate basin-fill episodes. Strong reflectors that form the basin floor appear to be folded. Flatlying reflectors within this fold were deposited unconformably upon the folded reflectors, and may represent post-deformational sedimentation. The eastern basin observed in the seismic sections north of Mesquite Valley is not evident on this line, and apparently does not extend this far south.

SUMMARY OF SEISMIC SECTIONS

Figure 46 is a fence diagram representing the general characteristics of the basins in Pahrump and Mesquite valleys as interpreted from the seismic sections. General information from a longitudinal seismic section (SSN-12) is added to tie together the other sections. Seismic section SSN-12 extends from the southern end of the Montgomery

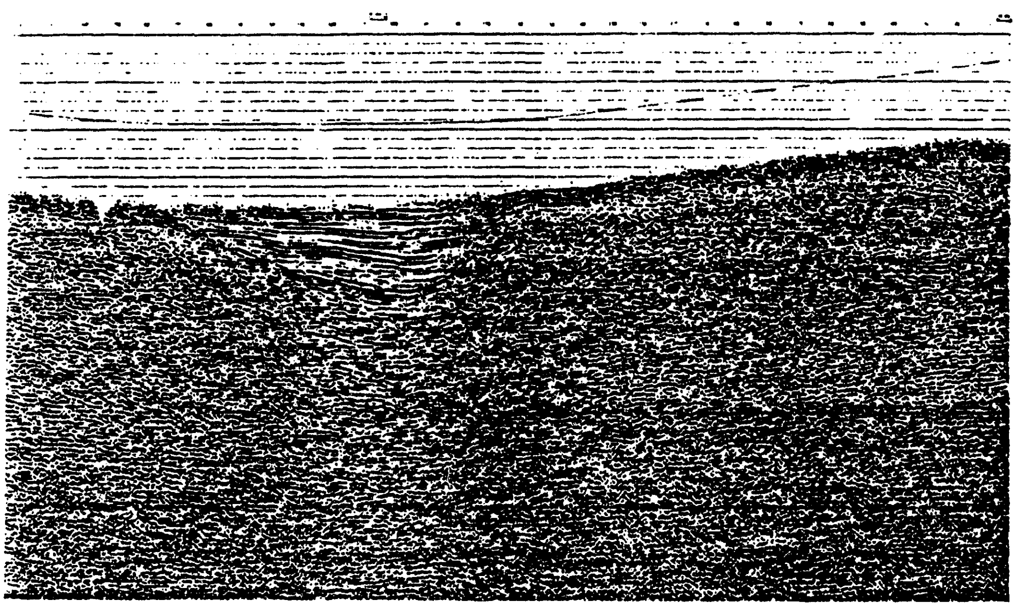


Figure 45a. Seismic section SSN-11. The overlay for this section, Figure 45b, is located in the back pocket.

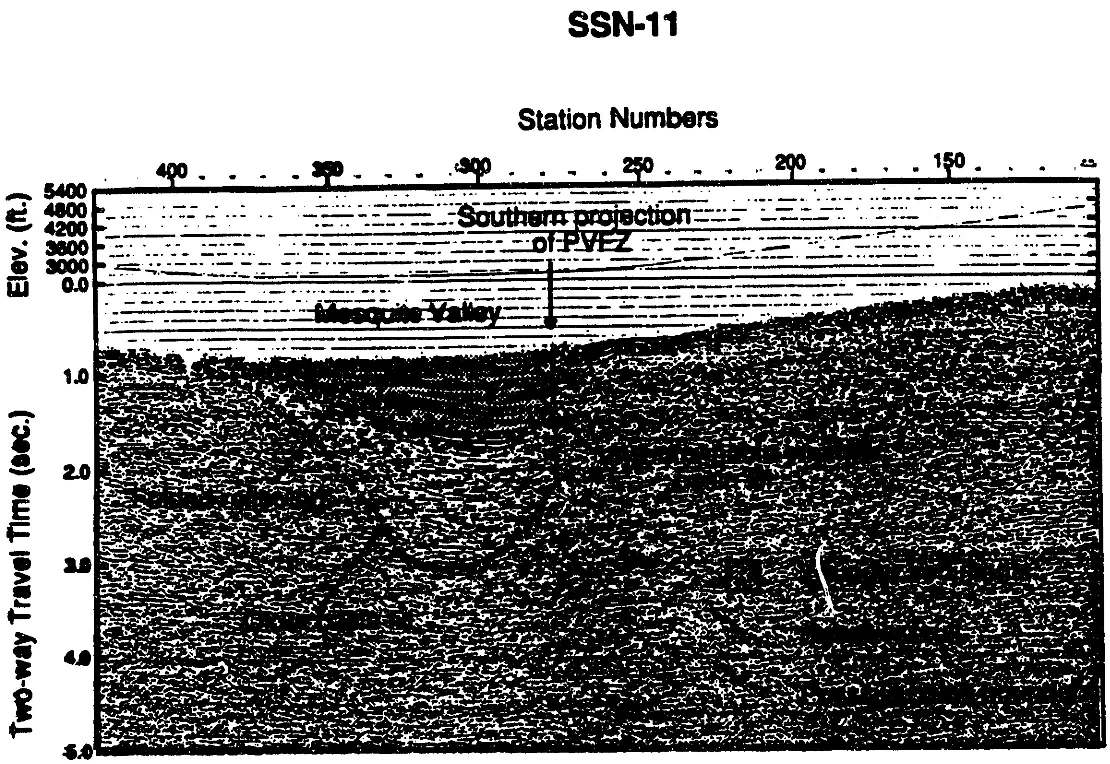


Figure 45b. Overlay showing interpretation of SSN-11.

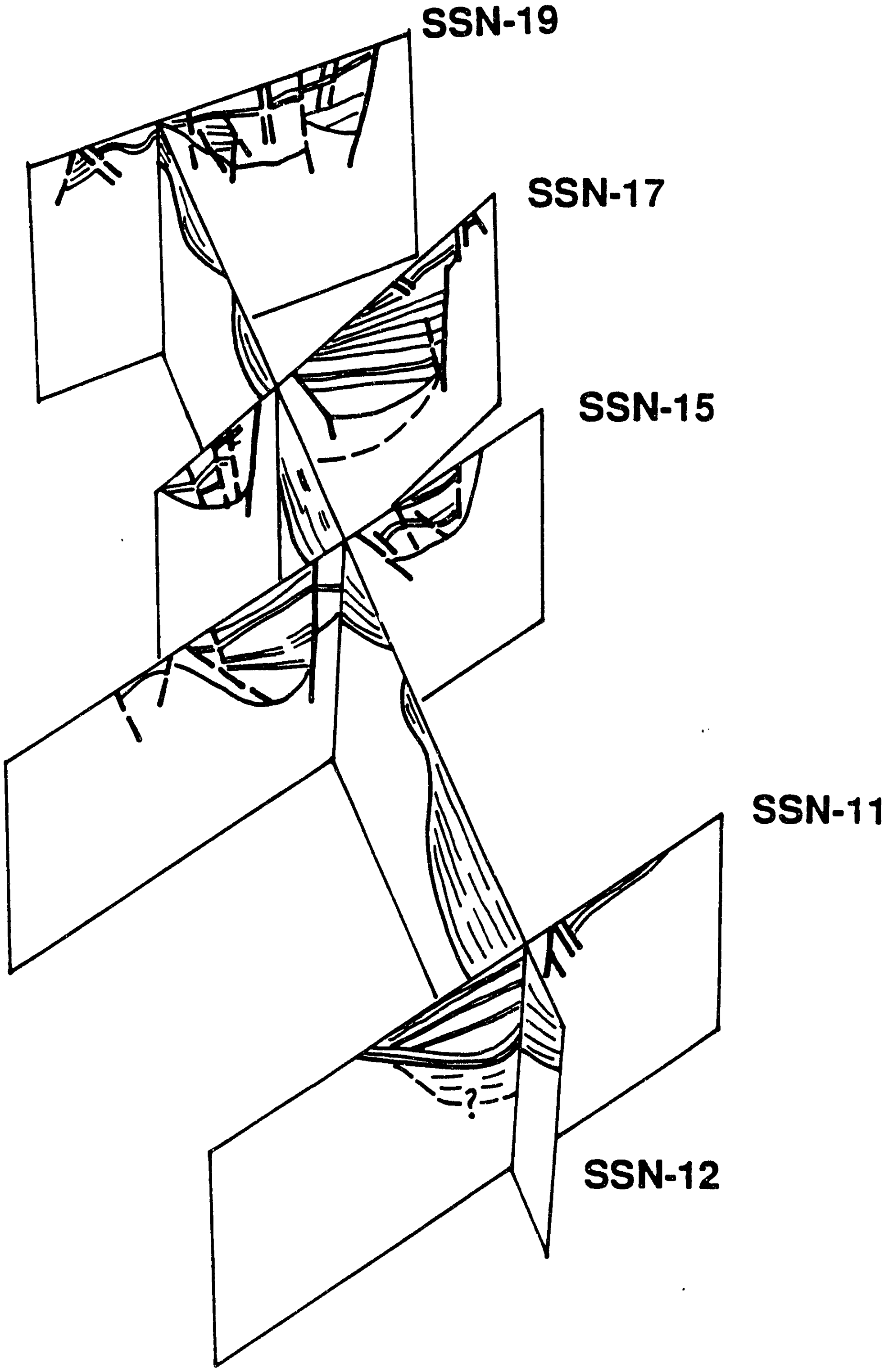


Figure 46. Fence diagram showing the relationship of basin features interpreted from the seismic lines.

Mountains southeast along the California-Nevada border, subparallel to the PVFZ (Figure 41). This section was not analyzed in detail due to possible complications caused by side-reflections off the PVFZ. However, seismic section SSN-12 provides useful general information on the geometry of the basin floor, and provides a cross-sectional perspective to the other four lines.

In general, a deep, broad basin in east-central Pahrump Valley has apparent northeast-dipping reflectors. This basin is bounded on the east by the northern WSMFZ, a moderately to steeply dipping normal fault system along the Spring Mountain range front. This major basin bounding fault has been active throughout deposition of the upper part of the basin fill, as evidenced by reflectors whose dips steepen with depth in the upper part of the basin. The basin is bounded on the west by the east-dipping flank of what appears to be a large horst block that lies beneath the PVFZ. Reflectors that dip north to northeast into this basin indicate down-to-the-west normal motion on the WSMFZ and that the locus of deposition for that basin has been against the Spring Mountains. In the central and deepest part of the basin, reflectors are uninterrupted by major faulting. However, in the southern part of the basin, high-angle faults and minor folds disrupt and deform the basin fill sediments.

The long, narrow horst that roughly coincides with the PVFZ extends at least as far south as seismic line SSN-15, at the south end of Pahrump Valley. There is no surface expression of this horst in Pahrump Valley. The horst may represent an elongate sliver of bedrock buried beneath the valley floor, a zone of basin fill that is highly disrupted by high-angle, strike-slip faults of the PVFZ, or a horst formed within the basin fill sediments. A bouguer gravity map compiled by Wright (1989) after gravity data from Bracken and Kane (1982), Chapman et al. (1975), Healey (1973), Healey et al. (1980), and Kane et al. (1979), shows no indication of buried bedrock beneath the PVFZ but instead shows some evidence of a basin south of the Pahrump playa. Mapping of the Quaternary faults in Pahrump Valley gave no indication of an east dipping, high-angle fault along the east side of the PVFZ. I therefore interpret the horst-like structure to be a zone of high-angle faulting where the PVFZ has behaved as a broad oblique shear, disrupting the basin stratigraphy and possibly downdropping originally continuous basin reflectors into a fault-bound graben or half graben, west of the PVFZ. Seismic section SSN-19 (Figure 42) shows some indication that this broad shear, coincident with the southern PVFZ, may be aligned along the hinge surface of a broad antiformal fold.

West of the horst, a basin has formed south of the

Pahrump playa. Reflectors in this basin show no preferred dip direction, dip at low angles, and are cut by high angle faults. I suggest that this basin was once continuous with the deeper basin to the east and that the basin reflectors were initially continuous with reflectors to the east. In effect, the PVFZ has separated a continuous basin into two sub-basins.

INTERPRETATION OF BASIN HISTORY

The two separate basins shown by the seismic sections may have once been part of one broad basin, and later split into two sub-basins by a zone of extreme shear along the PVFZ. Seismic reflection profile SSN-17 across the eastern Pahrump basin indicates that there may have been two episodes of deposition. The deeper basin fill has uniformly spaced reflectors that may have been deposited in a quasi-stable basin and may represent an episode of deposition following the initial opening of Pahrump valley. The spacing of reflectors in the deepest parts of the basin (see SSN-17, Figure 43 and SSN-15, Figure 44) is relatively constant, arguing against syndepositional tilting of the deeper valley fill. Seismic section SSN-17 (Figure 43) shows some indication that the shallower reflectors may converge to the west, indicating that syndepositional tilting of the younger part of the basin fill occurred.

East-dipping Plio-Pleistocene(?) basin fill sediments exposed at the surface in the southeast part of the Pahrump basin underlie a broad pediment. Two possible explanations for the uplift, exhumation and pedimentation of the Plio-Pleistocene(?) sediments in southeast Pahrump Valley are; 1) uplift was initially basin wide, and related to isostatic rebound along the footwall of a major low-angle detachment system, or 2) uplift was more local and was related to localized compression along the dextral PFS.

It is possible that uplift and east tilting of Plio-Pleistocene(?) basin fill sediments was produced by localized isostatic rebound near a breakaway zone of a major detachment system along the west flank of the Spring Mountains (Wernicke et al., 1988; Figure 47). The shallow east dip of the exposed Plio-Pleistocene(?) section and the formation of the pediment may represent a period of minor rebound followed by a period of tectonic stability. A period of gentle folding followed by a period of tectonic stability could produce the same effect. Seismic sections SSN-15 (Figure 44) and SSN-11 (Figure 45) shows broad folds within the older basin fill strata. These areas of folding are not related to kinks or bends in the present trend of the PFS. Either isostatic rebound and/or localized folding may have been responsible for the uplift and tilting of the sedimentary section exposed in southeastern Pahrump Valley.

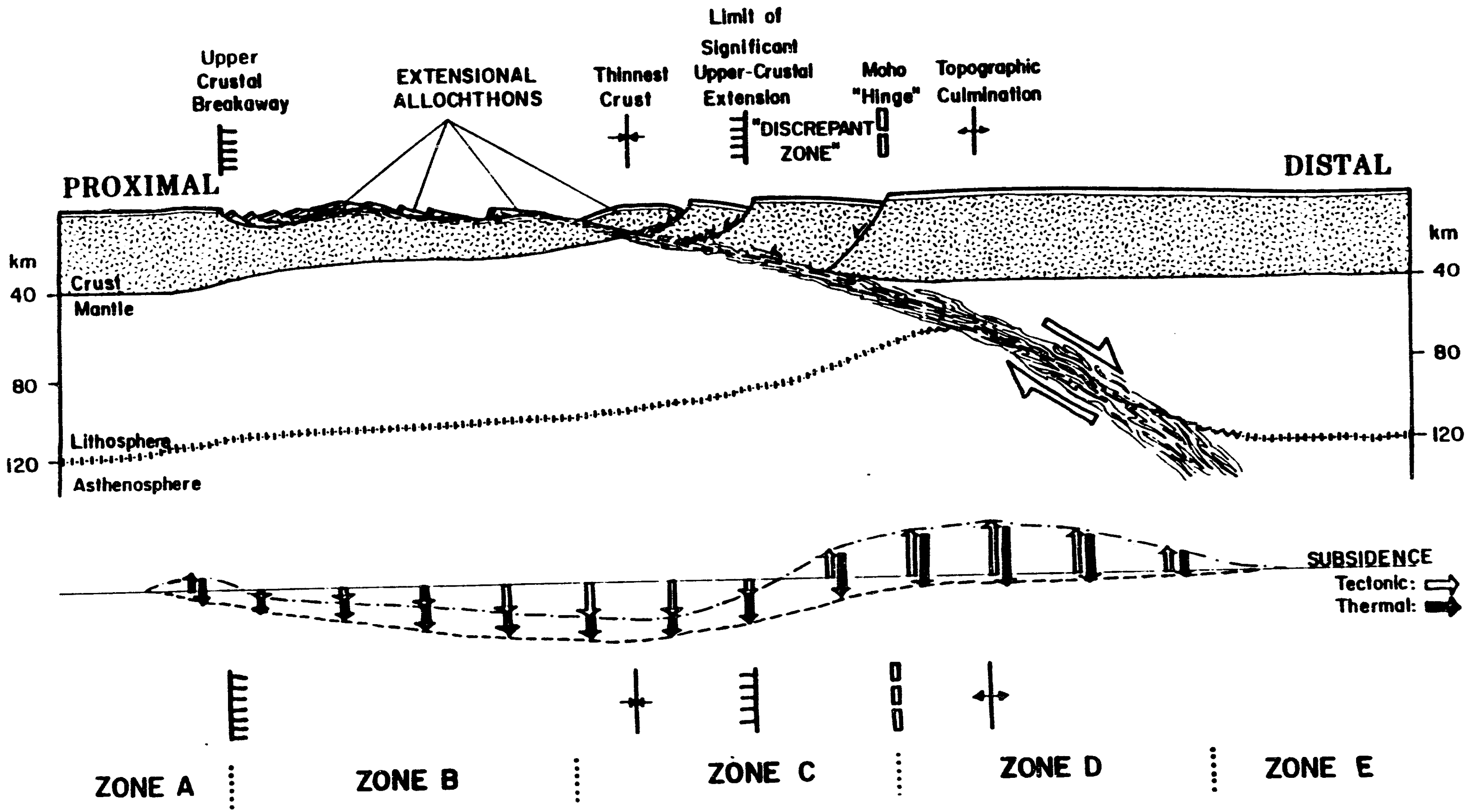


Figure 47. Diagram showing the location of the predicted slightly rebounded region near an upper crustal detachment zone. (Modified from Wernicke, 1985).

The pedimentation of the uplifted Plio-Pleistocene strata implies a period of tectonic stability. The pediment is now being dissected by arroyos draining into the Pahrump playa. Since the present day drainage of Pahrump Valley is entirely internal, an external drop in base level cannot be invoked as cause for the dissection. West-side-down normal faults west of the pediment causing a drop in drainage base level may be responsible this modern episode of downcutting.

A major gravity low occurs in the northeastern part of Pahrump Valley, between the PVFZ and the WSMFZ (Figure 48). Seismic section SSN-17 (Figure 43) shows that the gravity low is coincident with a depositional basin beneath this part of the valley. Sediments exposed in this part of the basin are older than the sediments of Pahrump and Stewart valley playas since they are dissected by modern washes that drain into the playas, but younger than the Plio-Pleistocene(?) sequence in southeastern Pahrump Valley since they are inset into the older deposits. This suggests that this basin has been an active depocenter in the recent past. The gravity data and the syndepositional tilting of the shallower valley fill suggests that the shallower part of the basin in northeast Pahrump Valley was formed along extensional faults related to the shear system now active in Pahrump Valley, and represents a pull-apart basin as proposed by Burchfiel et al., (1983) and Wright (1989), (Figure 49).

ENFZ, East Nopah fault zone; MM, Montgomery Mountains; NR, Nopah Range; RSR, Resting Spring Range; PVFZ, Pahrump Valley fault zone; SM, Spring Mountains; WSMFZ, West Spring Mountain fault zone.

Figure 48. Bouguer gravity contours (in milligals) superimposed on Quaternary faults of the Pahrump fault system. Bouguer gravity compiled by Wright (1989), from gravity data provided by Bracken and Kane (1982); Chapman et al. (1975); Healey (1973); Healey et al. (1980); and Kane et al. (1979).

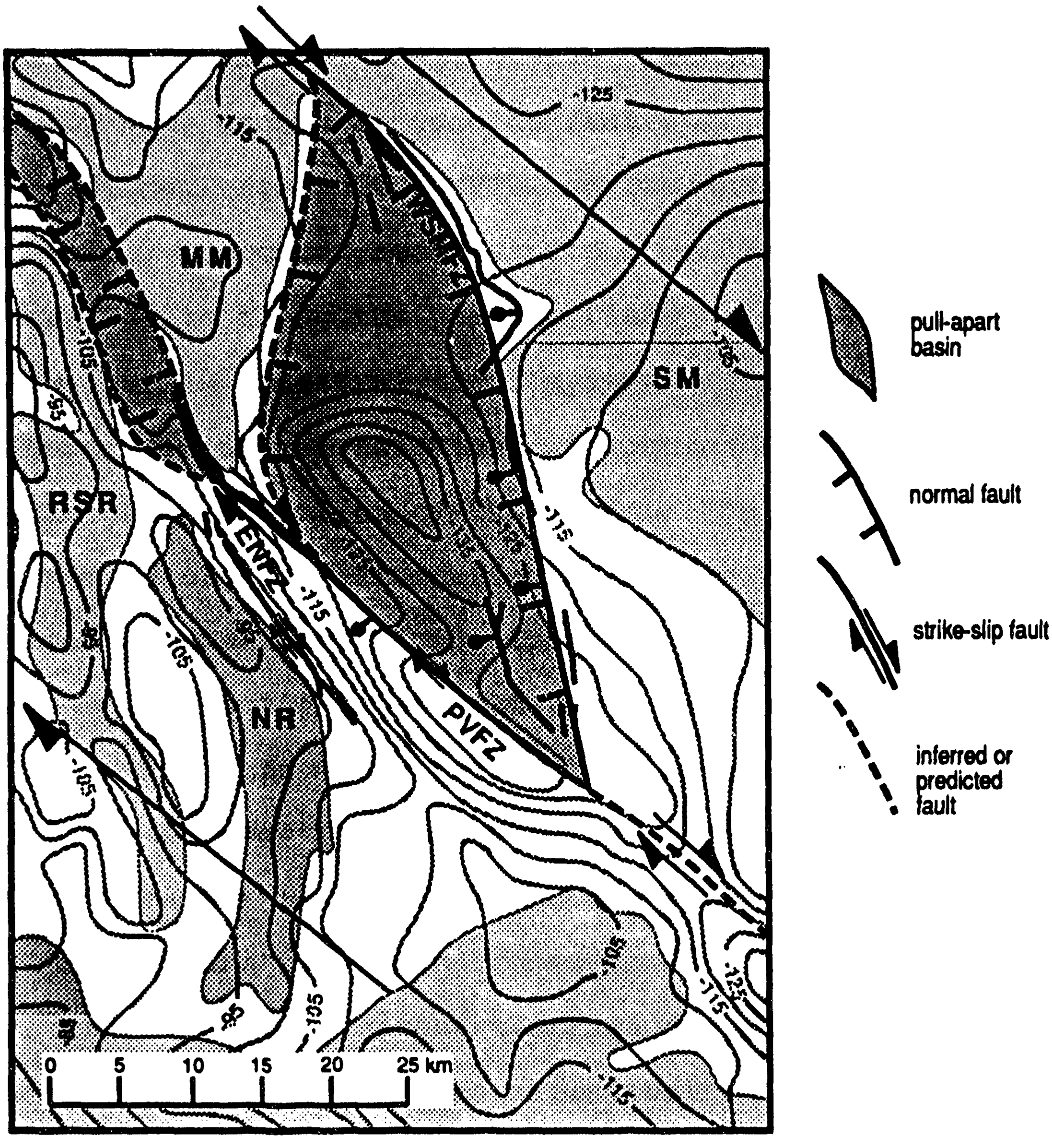


Figure 49. Fault and basin geometry suggesting northern Pahrump Valley and Stewart Valley are pull-apart basins.

The bounding fault east of the gravity low coincides with the normal WSMFZ, and on the southeast side of the gravity low, probable bounding faults coincide with faults transitional between the PVFZ and the WSMFZ. These normal faults may represent reactivation of older breakaway zone normal faults along the western flank of the Spring Mountains, but in a dextral shear system. Seismic line SSN-17 (Figure 43) shows a relatively intact package of reflectors in the deepest portion of the basin. The lack of major disruption of the basin reflectors shows that most of the faulting takes place along discrete faults and is not pervasively distributed throughout the basin.

Gravity data (Figure 48) and seismic section SSN-15 (Figure 44) show that a basin occurs just southeast of the Pahrump Valley playa. The generally flat-lying reflectors in this western basin are broken up by high angle faults. The reflectors may represent strata deposited in response to the opening of a symmetric graben west of the PVFZ. However, the reflectors are of a similar intensity, thickness and spacing as reflectors east of the PVFZ. This observation, together with the lack of a significant difference in the gravity values, suggests that the reflectors are part of the same stratigraphic package represented by the deep basin reflectors east of the PVFZ. These sediments are not exposed west of the PVFZ. The sediments have been downdropped and disrupted by high-angle faults west of the PVFZ and beneath the Pahrump playa, implying that a significant down-to-the-west normal component of movement has occurred along the PVFZ. Active faulting along the PVFZ and the ENFZ, the linearity of the west edge of the Pahrump playa, and en echelon vegetation lineaments at the north end of the playa imply that active high-angle faults lie hidden beneath the young playa sediments. The modern depocenter in Pahrump Valley lies west of the PVFZ. Downdropping of this basin west of the PVFZ has lowered the local base level, and is responsible for the current dissection of the pediment formed on the exhumed Plio-Pleistocene(?) basin fill.

A gravity low coincides with Stewart Valley (Figure 48). Stewart Valley is bounded by active faults on the southeast, and by strong vegetation lineaments on the east and west which may represent active faults. East-dipping structures on the west end of SSN-19 (Figure 42) may be the southern projection of buried faults that bound the west side of Stewart valley. The active faults in Stewart Valley strike about 10° more northerly than the main alignment of the PVFZ. The orientation of Stewart Valley suggests it may have opened along an extensional bend in the trend of a dextral shear system, and lends credence to the right-lateral interpretation for the PVFZ. The orientation of Stewart Valley and the gravity low beneath Stewart Valley both support the interpretation that Stewart Valley has opened as a pull-apart basin along a right bend in the PVFZ (Figure 49).

The down-to-the-west normal component on the PVFZ has created an active depocenter in Pahrump playa. This young depocenter and a basin beneath northern Mesquite Valley, shown by seismic section SSN-11 to be bounded by a high-angle fault on the east, are interpreted as examples of basins formed by minor vertical displacements along the PVFZ. The axes of these basins appear to be subparallel to the trend of the PVFZ (Figure 48), suggesting that the PVFZ has had a slight extensional component during its most recent history. Seismic section SSN-11, which is nearly perpendicular to the axis of Mesquite Valley, shows a broad fold in the deeper reflectors beneath Mesquite Valley, that may have had some relation to the early genesis of the valley. However, temporal and spatial changes in areas of extension and shortening within a given basin are characteristics of strike-slip faults (Christie-Blick and Biddle, 1985) and lends credence to the interpretation of the PFS as primarily a dextral shear zone.

TECTONIC IMPLICATIONS

Stewart (1988) included the PFS in the Inyo-Mono section of the Walker Lane belt. The ENFZ strikes N35°W, parallel with the Nopah range front. This fault zone strikes slightly more northerly than the right-lateral Furnace Creek fault zone (strike N45°W from Brogan et al., 1988), and the right-lateral segments of the northern Death Valley fault zone (N40°W; Sawyer, 1989). Both of these faults have had Quaternary displacement (Cemen et al., 1985; Brogan et al., 1988; Sawyer, 1989). The ENFZ is interpreted to be a primarily right-lateral strike-slip fault with no significant normal component.

The PVFZ strikes generally N45°W, subparallel to the right-lateral Furnace Creek fault (N45°W, Brogan et al, 1988), and subparallel to the right-slip regions of the Northern Death Valley fault zone (N40°W; Sawyer, 1989) and the Fish Lake Valley fault zone (N50°W; Sawyer, 1989). The PVFZ is probably the principal displacement zone for the PFS. The trace of the PVFZ trends south toward the right-lateral State Line fault of Hewett (1957), and northward into the active fault system in the southern Amargosa Valley (Donovan, 1990). The PVFZ is aligned along a major dextral shear zone proposed by Schweickert (1989) that may extend from the State Line fault northward through Crater Flat (Figure 6). Schweickert (pers. comm., 1990) suggested that this shear zone may have had as much as 25 km right-lateral displacement since 11 Ma and may have been active during times of volcanism 3.2, 1.2 and .03 Ma. The PVFZ can be best interpreted as a primarily right-lateral strike-slip fault with a down-to-the-west normal component.

The WSMFZ trends N12°W, has consistently west-side-down offsets, a sinuous fault trace that mimics the geometry of the Spring Mountains range front, sharp bends in the fault trace, and numerous grabens formed along the fault. The trends of the Dyer segment of the Fish Lake Valley fault and the trend of the southern Death Valley fault zone are both similar to the average trend of the WSMFZ.

The central Death Valley fault zone has many of the geomorphic features characteristic of dip-slip faults. The Dyer segment of the Fish Lake Valley fault zone forms the eastern rangefront of the White Mountains. This segment has significant relief on scarps, up to 80 to 100 m, and has had substantial vertical displacement (Sawyer, 1989). By analogy with these faults, the WSMFZ is interpreted as a primarily west-side-down normal fault.

The PFS is best described as a divergent dextral shear zone, consistent with Stewart's (1988) hypothesis that the PFS is an active part of the southern Walker Lane belt. This interpretation also agrees with Schweickert's (1989) hypothesis of a major dextral shear zone extending from Crater Flat southward into the State Line fault.

The evidence for Quaternary activity on the PFS suggests that at least parts of the major shear zone are currently active. The younger fault scarps in northern Pahrump Valley and older scarps in southern Pahrump Valley may indicate that activity is currently migrating northward along the major shear zone. Folding of basin reflectors along the PVFZ suggests there may be spatial and temporal fluctuations in areas of compression and extension along the fault. It is possible that the PVFZ experiences non-systematic spatial and temporal fluctuations in the locus of activity.

Wright (1984) noted that Quaternary ground ruptures are much more abundant west of the Black Mountains escarpment than east of it. However, prior to Wright's study, the Pahrump fault system was poorly recognized and Quaternary ground rupture had not been demonstrated for the PFS. This study of the PFS indicates there are abundant Quaternary ruptures in Pahrump and Stewart Valleys, and that there may be more Quaternary activity east of the Black Mountains than previously recognized. Donovan (1990) described an active fault system in Ash Meadows in the southern Amargosa Desert, that trends into the PFS. This fault zone also has evidence for probable Quaternary activity on many of the faults.

Wernicke et al. (1988) proposed that the Pahrump basin opened between 10 and 15 m.y. ago with the initiation of the Death Valley normal fault system. The rate of early Neogene extension within the Death Valley normal fault system

10-15 Ma was probably higher (20-30 mm/yr) than the current extension rate of less than 10 mm/yr, and the direction of extension was more easterly than the extension direction of N73° +/- 12°W averaged over the last 15 Ma (Wernicke et al., 1988).

The deep reflectors observed in SSN-17 may represent sediments deposited in this early formed basin, although evidence for the listric nature of the faults is lacking. The deep reflectors are uniformly spaced and show uniform dips indicating that tilting occurred after deposition of the sediments. These deep reflectors dip eastward in the vicinity of the PVFZ. The upper reflectors observed in seismic section SSN-17 show syndepositional tilting in that the dips steepen with depth in the section, the reflectors converge to the west, and reflectors near the top of the section are subhorizontal. The tilting of these reflectors appears to have been associated with syntectonic deposition along a listric normal fault, but this can be explained by a reactivation of breakaway zone normal faults at the Spring Mountains Range front.

Wright (1984) proposed that severe extension in the vicinity of the Kingston Range ended prior to 14 Ma, as there, the major detachment surface and associated faults are truncated by the 14 Ma Kingston Peak pluton. He stated that tilting of the Resting Spring Range post-dates 12 Ma dacitic flows and pre-dates a 9 Ma rhyolitic ash-flow tuff. Therefore, maximum extension for this region occurred from 12 to 9 Ma. Wright (1984) proposed that major crustal extension has migrated westward, and the area around and west of the Black Mountains had experienced major extension in the range of 9 to 4 Ma, and that normal faulting in the Coso Range, Owens Valley and the eastern Sierra Nevada occurred mainly in the interval 4 Ma to present. The absence of major normal faulting in Pahrump Valley possibly since Plio-Pleistocene time supports Wright's hypothesis that major extension had ended prior to Plio-Pleistocene time.

The area from the Spring Mountains breakaway zone and immediately west fall into zone A of Wernicke's (1985) normal simple shear model for highly extended terrains (Figure 47). The model predicts that a small amount of localized isostatic rebound occurs along the breakaway zone of major detachment systems. This model could explain the uplift and exhumation of the Plio-Pleistocene(?) section exposed in southeast Pahrump Valley. The cessation of rebound at isostatic equilibrium may be represented by the tectonic hiatus in which the pediment in southeast Pahrump Valley was formed.

It is likely that the present Pahrump fault system is superimposed upon, and generally unrelated to the proposed

Death Valley normal fault system responsible for the initial opening of Pahrump Valley. One possible exception to this is that the WSMFZ may represent reactivation of earlier listric normal faults within the breakaway zone of the Death Valley normal fault system.

Wernicke et al. (1988) did not account for strike-slip faults when they reconstructed the initial opening of the Pahrump basin. If the strike-slip faults in Pahrump Valley are accommodation faults related only to zones of differential extension, the faults would be confined only to the area of high extension. Though the Quaternary faults along the PFS are confined to Pahrump and Stewart Valleys, there is evidence for Quaternary activity in the southern Amargosa Desert, and this along with the inferred extension of a dextral shear zone to the north and south as proposed by Schweickert (1989) extends the zone of strike-slip faulting outside of the proposed zone of extensional faulting.

Reflectors in the basin in southwest Pahrump Valley show no systematic tilting, implying that the deposition of the sediments in this basin took place after major low-angle listric faulting had ceased in the Pahrump basin, and that the PVFZ is not a west-dipping listric normal fault zone.

Wernicke et al. (1988) suggested that the Resting Spring and Nopah Ranges have been translated westward, away from the Spring Mountains along low-angle normal faults.

The Nopah and Resting Spring ranges are located within the upper plate of the proposed DVNFS initiating at the Spring Mountains. The location of the active PFS lies entirely with the Pahrump basin, east of the Nopah and Resting Spring ranges and west of the Spring Mountains. Thus, the PFS cuts only the lower plate of the DVNFS (Figure 50). Therefore, the PFS must have been superimposed upon the earlier extended terrain, and cannot be viewed as a shallow accommodation fault separating zones of extension.

A change in the tectonic style of the southern Great Basin is predicted by a change in relative plate motion between the Pacific and North American plates. This change in plate motion occurred 3.6 to 3.8 Ma, and Argus and Gordon (1990) predicted up to 10 mm/yr of N60°W right-lateral displacement should be distributed throughout the region between the Sierra Nevada block and the Colorado Plateau. Nitchman et al. (1990) cited several examples from the triangular region coincident with the DVNFS that supports this change in tectonic style since ~4 Ma.

SUMMARY

The timing of tectonic events in Pahrump Valley is poorly constrained. Table 2 summarizes the Cenozoic history of the Pahrump basin. Following Wernicke et al.'s (1988) hypothesis for the opening of the Pahrump basin, the basin

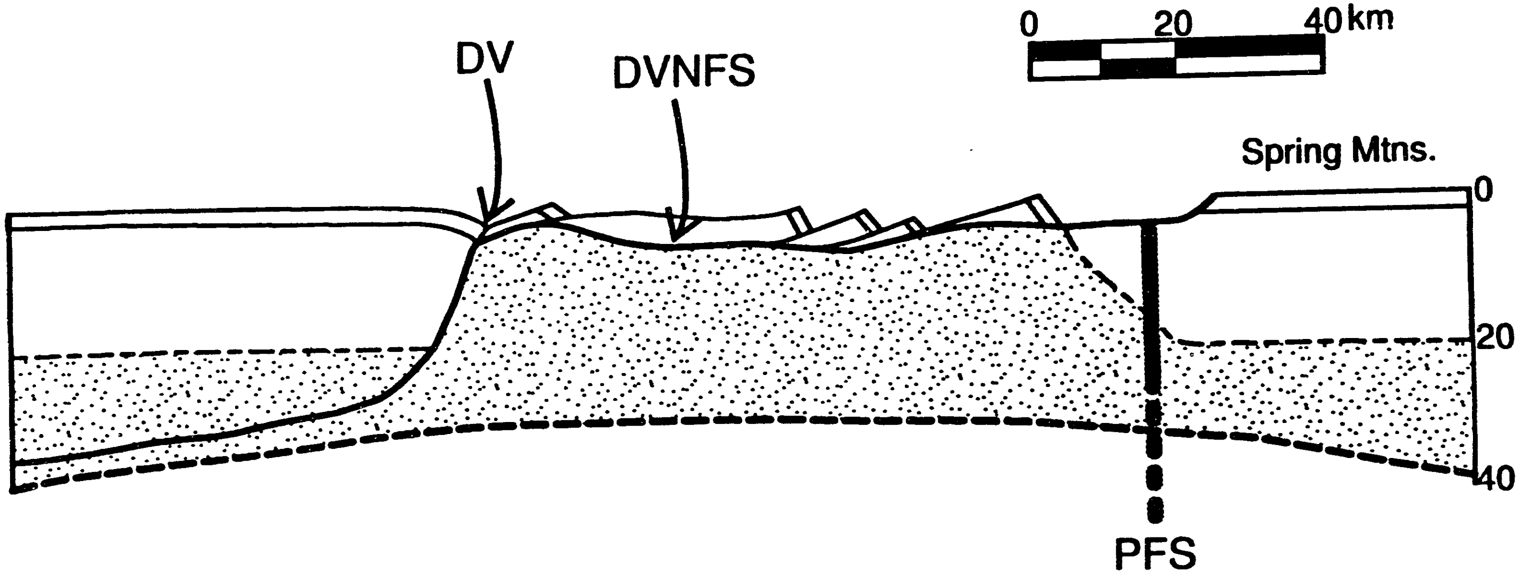


Figure 50. Location of the PFS showing that the PFS cuts only the lower plate of the DVNFS. Modified from Asmerom et al., 1990.

Table 2. Summary of proposed tectonic and depositional events in Pahrump Valley.

Time	Event	Mechanism	Evidence
L. Mesozoic to M. Cenozioc	Walker Lane style dextral shear in Pahrump Valley	Oblique subduction of Pacific plate beneath the North American plate causing right-lateral faulting along and in back of a back-arc basin (?) (Stewart, 1988).	Right-lateral movement on NW-striking Stewart Valley fault as evidenced by Cenozoic folds oblique to fault, faults and folds are older than Cenozoic rocks exposed in the Northern Resting Springs Range.
L. Ceno 10-15 Ma	Initiation of DVNFS, Opening of Pahrump Valley, East tilting of Nopah and Resting Spring ranges, deposition of deep basin fill. Strike slip faulting may be contemporaneous with detachments (Burchfiel, 1983) or may have caused localized detachments (Wright, 1989).	Extension related to change in stress field. Pacific plate subduction has ended and wide, soft plate boundary may have caused deformation in the Basin and Range province (Atwater, 1970).	Most tilting of Resting Spring Range post dates ~12 Ma dacitic flows and pre-dates ~9 Ma ash flows (Wright, 1984). Peak extension in DVNFS 14-4 Ma (Cemen et al., 1985). May be linked with the Amargosa rift initiating pre-13.2 Ma (Wright, 1989). Alignment of gravity lows along the PVFZ.
10-5 Ma	Slow down of extension. Initiation of modern PFS Uplift of Tertiary (?) basin fill in Pahrump and pedimentation of uplifted section (may be contemporaneous with formation of Plio-Pleistocene Ivanpah Upland.) Initial formation of Mesquite and Stewart Valley by folding (?).	Changing plate motion (?)	1-12 Ma volcanic units become progressively more steeply tilted westward from the Nopah range to the Black Mountains recording westward cessation of large magnitude extension (Wright, 1983). Post-9 Ma tilting of Resting Spring Range (Wright, 1983). Post-9 Ma Tertiary overlap of extensional structures in Resting Springs Range and Post - 4 Ma Tertiary overlap in Furnace Creek Wash (Wright et al., 1983, 1984; Cemen et al., 1985). Less than 5 deg. tilt of basin fill in Pahrump Valley.

Table 2 (Cont.) Summary of proposed tectonic and depositional events in Pahrump Valley.

Time	Event	Mechanism	Evidence
~4 Ma	Formation of Stewart and northern Pahrump Valleys as pull-aparts. Major activity on strike-slip faults, reactivation of WSMFZ. Faulting of pediment in southeast Pahrump Valley. Syntectonic deposition of Younger Valley basin fill.	Major change in plate motion to slightly constrictional, imposing shear on southern Great Basin	Regional break-up of erosional surfaces in the Western Great Basin into modern Basin and Range topography post-4 Ma (Nitchman et al., 1990). VLBI data suggesting up to10mm/yr NW dextral shear east of the Sierra Nevada (Argus and Gordon, 1990).
present	Continued dextral shear on PFS. Deposition in Pahrump and Stewart Valley playas, dissection of pediment in southeast Pahrump Valley.	Continued slightly constrictional strain field.	Geomorphically youthful scarps and lineaments in young alluvium in northern Pahump Valley and Stewart Valley, dissection of the pediment in southeast Pahrump Valley, vegetation lineaments in the Pahrump and Stewart Valley playas, faulted alluvial fans of the east Nopah range front and the west Spring Mountains range front.

was initially opened along the breakaway zone of the Death Valley normal fault system, about 10-15 m.y. ago. During this time extension rates were high (20-30 mm/yr) and approximately northwest directed extension was dominant. A deep seated shear system beneath Pahrump Valley may have been in place at this time, but the high extension rates may have overwhelmed the lower strike-slip rates.

The PFS lies at the southern end of the Walker Lane Belt as delineated by Stewart (1988). The following evidence suggests that a generally northwest-trending dextral shear zone has been active beneath Pahrump Valley at least since the mid to late Tertiary: Extreme linearity of the PVFZ; alignment of the PVFZ with apparent dextral faults as far south as Ivanpah Valley and as far north as Crater Flat; probable opening of Stewart Valley, and northern Pahrump Valley as pull-apart basins; stratigraphic evidence for migrating depocenters; evidence from seismic reflection profiles for broad scale folding of deep reflectors indicating localized compression; evidence from seismic reflection profiles for distributed high-angle faulting; right-lateral offsets of Paleozoic rocks of up to 35 km; and the present fault geometry. Slowing of extension rates in the last 5-10 Ma and a change in relative motion at the North America/Pacific plate boundary 3.6 to 3.8 Ma (Nitchman et al., 1990) may have caused the reactivation of this shear zone as the active fault system now evident in the Pahrump basin.

RECOMMENDATIONS FOR FUTURE STUDIES

This study of the faults and basin history of Pahrump Valley and Stewart Valley is a first attempt at a synthesis of the late Cenozoic history of the region. Prior to this study, mapping of the faults in Pahrump was accomplished through a remote sensing analysis of faults in the basin (Liggett and Childs, 1973), and no attempt was made to relate these faults to the present basin morphology. Other studies regarding the tectonic history of the Pahrump basin involved correlation of Mesozoic thrust faults in the ranges bordering Pahrump Valley (Wernicke et al., 1988). Although Malmberg (1967) produced a reasonable reconnaissance level geologic map of the basin, no detailed stratigraphic description of maps of the Tertiary(?) and younger deposits exposed in Pahrump was produced. The present study concentrated on fault patterns and timing of the Pahrump fault system as well as interpretation of seismic reflection profiles to determine deep basin and fault geometries. As with most research projects, this study produced as many questions as answers and much work remains to determine the long term history of the Pahrump basin, as well as the current level of activity of the fault system.

The basin stratigraphy of Pahrump Valley needs to be mapped in detail. Pahrump is an excellent place for an analysis of Tertiary basin stratigraphy, since localized compression along the fault system and/or isostatic rebound has uplifted a considerable section of the older basin fill deposits. Detailed mapping may help to constrain offsets along faults, timing of fault events, and deformational structures related to the PFS. Analysis of the basin deposits might indicate their source area, and lead to a better understanding of the geometry and depositional history of the early Pahrump basin. Hewett's (1956) description of the Resting Spring formation exposed along the north flank of the Kingston Range suggests these deposits may be similar to deposits exposed in the dissected drainages near Browns Springs in Pahrump Valley. Correlation of this stratigraphy, which contains datable tuff deposits, may be useful for long term basin analysis as well as long term fault history.

J. Quade has begun mapping the late Wisconsin stratigraphy in the vicinity of Stump Spring, Browns Spring and Hidden Hills. His mapping reveals an extensive late Wisconsin history buried in restricted bodies of sediment inset into the older basin sediments. This mapping indicates an abundance of young datable deposits which might be used to constrain the timing of fault events in Pahrump. Quade's mapping is concentrated in the southern part of the basin, but similar deposits occur along the northeastern portion of the basin, along Highway 160 and in dissected packages along faults that splay off of the main PVFZ towards the WSMFZ (Location 30, Plate 1). These young deposits in the northeastern portion of the basin are faulted by down-to-the-west normal faults, and detailed mapping of the deposits may help constrain timing of fault events.

The northern portion of the PVFZ in northwestern Pahrump Valley, and southeastern Stewart Valley has many young scarps representing recent faulting events. Inspection of stream cutbanks in this area shows very homogenous sediments with no discernible bedding or stratigraphy. However, one shallow landfill excavation at the south end of Stewart Valley did show weak bedding of coarser and finer sediments. Trench excavations across one or more of these young fault splays may yield information on the subsurface geometry of the faults as well as bedding offsets. However, it is unlikely that datable materials will be discovered in these excavations. Placing limiting ages on fault events will therefore be difficult.

In one location along the ENFZ (Location 5, Plates 1 and 2), a west facing scarp has ponded young alluvium. This may be another good location for a trench excavation to explore subsurface fault geometry and magnitude of vertical offsets along the ENFZ.

A geomorphic map of the alluvial fans of the Spring Mountain range front may be useful in constraining timing of events and rates of activity for the WSMFZ. Janet Sower's (1986) mapping of the Kyle Canyon fan surfaces on the east flank of the Spring Mountains provides a reasonable basis for comparison of surface ages as the parent lithologies are similar, both being dominantly limestones. Air photo expression of the geomorphic surfaces along the Spring Mountains range front shows that these surfaces are geomorphically distinct. Possible age control for the fan surfaces could be provided from the Late Wisconsin paludal deposits exposed at the toe of a large alluvial fan of the Spring Mountains range front in northern Pahrump Valley which are dissected by the youngest alluvial fan deposits. Soils descriptions from these surfaces may also help constrain surface ages.

REFERENCES CITED

Asmerom, Y., Snow, J. K., Holm, D. K., Jacobsen, S. B., Wernicke, B. P., and Lux, D. R., 1990, Rapid uplift and crustal growth in extensional environments: An isotopic study from the Death Valley region, California: Geology, v. 18, p. 223-226.

Argus, D. F., and Gordon, R. G., 1990, The relationship between current Sierra Nevada-North America motion and the direction of maximum Great Basin extension: Geology, 1990 (in review).

Biddle, K. T., and Christie-Blick, N., 1985, Glossary - strike-slip deformation, basin formation, and sedimentation: *in* Biddle, K. T., and Christie-Blick, N., eds., *Strike-slip Deformation, Basin Formation and Sedimentation*, Society of Economic Paleontologist and Mineralogists, Special Publication No. 37, p. 377.

Brogan, G. E., Kellogg, K. S., and Terhune, C. L., 1988, Late Quaternary faulting along the Death Valley-Furnace Creek fault system, California and Nevada: U. S. Geological Survey Open File Report (in preparation).

Bracken, R. E., and Kane, H. F., Kingman Sheet, Bouguer gravity map of Nevada: Nevada Bureau of Mines and Geology Map 75.

Burchfiel, B. C., Hamill, G. S., and Wilhelms, D. I., 1983, Structural geology of the Montgomery Mountains and the northern half of the Nopah and Resting Springs Ranges, Nevada and California: Geological Society of America Bulletin, v. 94, p. 1359-1376.

Carr, W. J., 1984, Regional structural setting of Yucca Mountain, southwestern Nevada, and Late Cenozoic rates of tectonic activity in part of the southwestern Great Basin, Nevada and California: U.S. Geological Survey Open File Report 84-854, 109 p.

Cemen, I., Wright, L. A., Drake, R. E., Johnson, F. C., 1985, Cenozoic sedimentation and sequence of deformational events at the southeastern end of Furnace Creek strike-slip fault zone: *in* Biddle, K. T., and Christie-Blick, N., eds., *Strike-slip Deformation, Basin Formation and Sedimentation*, Society of Economic Paleontologist and Mineralogists, Special Publication No. 37, pp. 127-141.

REFERENCES CITED (cont.)

Christie-Blick, N., and Biddle, K. T., 1985, Deformation and basin formation along strike-slip faults: *in* Biddle, K. T., and Christie-Blick, N., eds., *Strike-slip Deformation, Basin Formation and Sedimentation*, Society of Economic Paleontologist and Mineralogists, Special Publication No. 37, pp. 1-34.

Chapman, R. H., Healey, D. L., and Troxel, B. W., 1975, Death Valley sheet, Bouguer gravity map of California: California Division of Mines and Geology.

Donovan, D., 1990, Active fault patterns of the southern Amargosa Desert, Nye County, Nevada: Geological Society of America Abstracts with Programs, v. 22, n. 3, p. 18.

Hamill, G. S., IV, 1966, Structure and stratigraphy of the Mt. Shader Quadrangle, Nye County, Nevada-Inyo County, California: Ph. D. Thesis, Rice University, Houston, Texas, 83 p.

Healey, D. L., 1973, Kingman sheet, Bouguer gravity map of California: California Division of Mines and Geology.

Healey, D. L., Wahl, R. R., and Oliver, H. W., 1980, Bouguer gravity map of Nevada Death Valley sheet: Nevada Bureau of Mines and Geology Map 69.

Hewett, D. F., 1956, Geology and mineral resources of the Ivanpah Quadrangle California and Nevada: U. S. Geological Survey Professional Paper 275, 172 p.

Hoffard, J. H., 1990, Quaternary fault patterns in Pahrump Valley NV, and Stewart Valley CA: Geological Society of America Abstracts with Programs, v. 22, n. 3, p. 29.

Kane, M. F., Healey, D. L., Peterson, D. L., Kaufmann, H. E., and Reidy, D., 1979, Las Vegas Sheet, Bouguer gravity map of Nevada: Nevada Bureau of Mines and Geology Map 61.

Liggett, M. A., and Childs, J. F., 1973, Evidence of a major fault zone along the California-Nevada state line, 35°30' to 36°30' N. latitude: Argus Exploration Company, NASA Report of Investigation CR-133140, E73-10773, 13 p.

REFERENCES CITED (cont.)

Malmberg, G. T., 1967, Hydrology of the valley-fill and carbonate rock reservoirs, Pahrump Valley, Nevada-California: U. S. Geological Survey Water Supply Paper 1832, 47 p.

McKittrick, M. A., 1988, Surficial geologic map of the Resting Spring and Nopah Ranges, Inyo County, California, and Nye County, Nevada: U. S. Geological Survey Miscellaneous Field Studies Map MF-1941.

MIT Field Geophysics Course, 1985, A geophysical study of Mesquite Valley: Nevada-California Border: Journal of Geophysical Research, V. 90, p. 8685-8689.

Nitchman, S. P., Caskey, S. J., and Sawyer, T. L., 1990, Change in great basin tectonics at 3 to 4 Ma--A hypothesis: Geological Society of America Abstracts with Programs, v. 22, n. 3 p. 72.

Peterson, F. F., 1981, Landforms of the Basin and Range province, defined for soil survey: Nevada Agricultural Experiment Station, University of Nevada Reno, Technical Bulletin 28.

Schweickert, R. A., 1989, Evidence for a concealed dextral strike-slip fault beneath Crater Flat, NV: Geological Society of America Abstracts with programs, v. 21. p. 90.

Slemmons, D. B., 1977, State-of-the-Art for Assessing Earthquake Hazards in the United States: Report 6, Faults and Earthquake Magnitude: Mackay School of Mines, University of Nevada, Reno.

Sowers, J., 1986, Geomorphic map of the Kyle Canyon alluvial fan, Clark County, Nevada: U. S. Geological Survey Open File Report 86-210, 9 pp.

Stewart, J. H., 1988, Tectonics of the Walker Lane Belt, western Great Basin: Mesozoic and Cenozoic deformation in a zone of shear: *in* Ernst, W. G., ed., *Metamorphism and Crustal Evolution of the Western United States*, Ruby Volume VII, Prentice-Hall, New Jersey, p. 683-713.

Tchalenko, J. S., and Abraseys, N. N., 1970, Structural Analysis of the Dasht-e Bayaz (Iran) earthquake fractures: Geological Society of America Bulletin, v. 81, p. 41-60.

Wernicke, B., 1985, Uniform-sense normal simple shear of the continental lithosphere: Canadian Journal of Earth Sciences, v. 22, p. 108-125.

Wernicke, B., Axen, G. J., and Snow, J. K., 1988, Basin and Range extensional tectonics at the latitude of Las Vegas, Nevada: Geological Society of America Bulletin, v. 100, p. 1738-1757.

Wright, L. A., Troxel, B., W., Burchfiel, B. C., Chapman, R. H., And Labotka, T. C., 1981, Geological cross section from the Sierra Nevada to the Las Vegas Valley, eastern California to southern Nevada: Geological society of America Map and Chart Series, MC-28M.

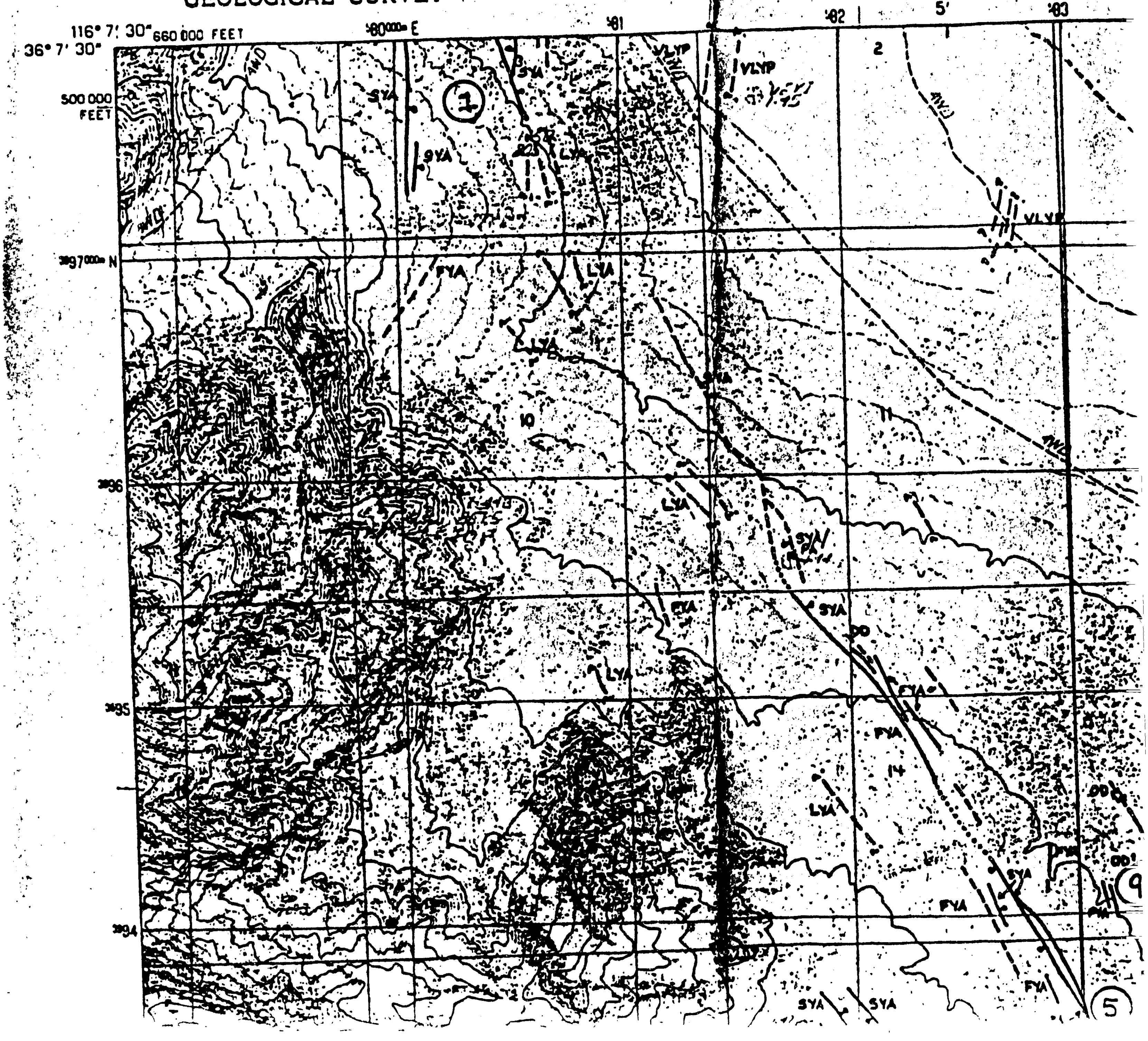
Wright, L. A., Drake, R. E., and Troxel, B. W., 1983, Contrasting space-time patterns of extension-related, late Cenozoic faulting, southwestern Great Basin: Geological Society of America Abstracts with Programs, v. 15, p. 287.

Wright, 1984, Evidence for the westward migration of severe Cenozoic extension, southwestern Great Basin, California: Geological Society of America Abstracts with Programs, v. 16, p. 701.

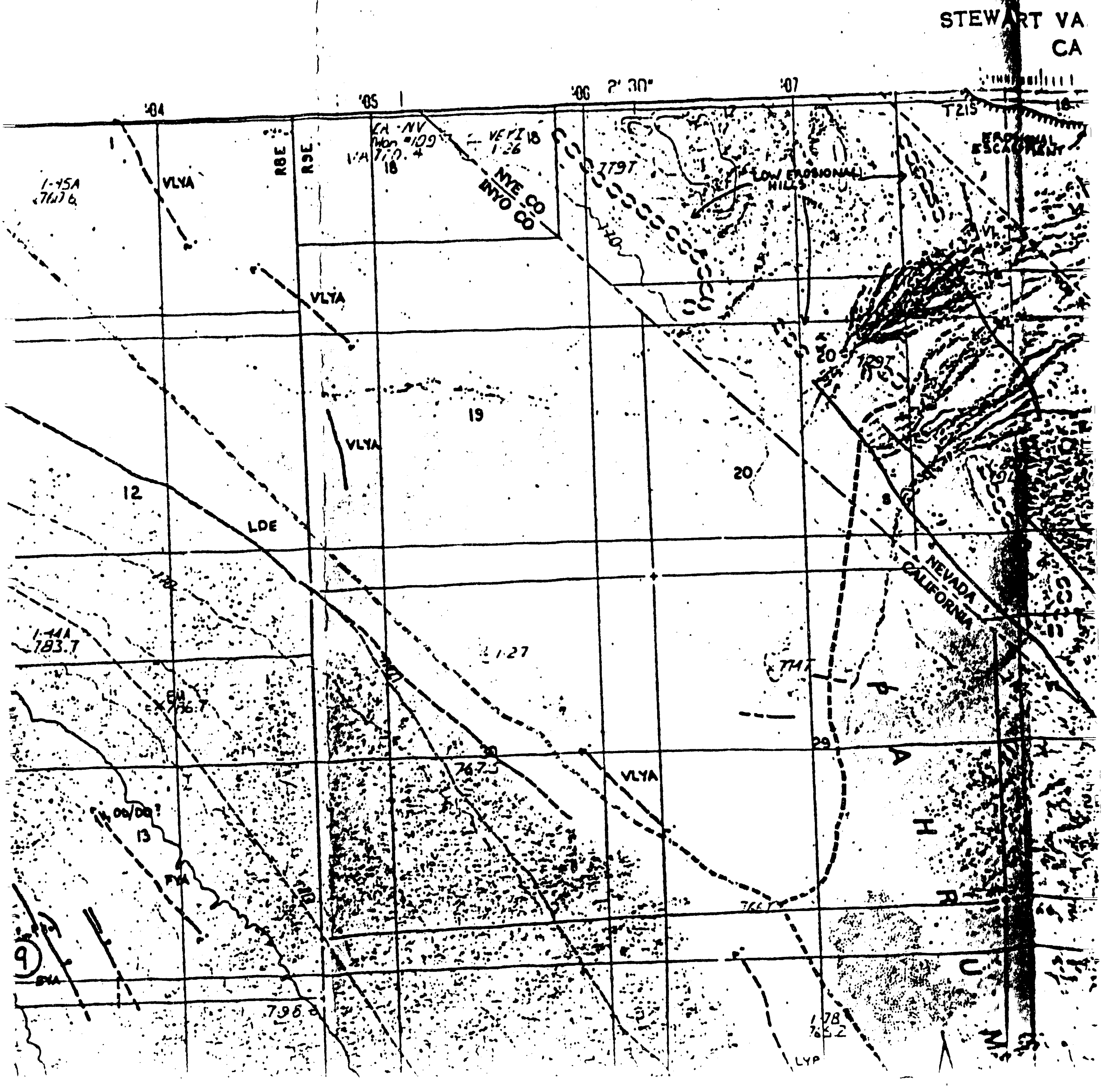
Wright, L. A., 1989, Overview of the role of strike-slip and normal faulting in the Neogene history of the region northeast of Death Valley, California-Nevada: *in* Ellis, M. A., ed., *Late Cenozoic Evolution of the Southern Great Basin,* Nevada Bureau of Mines and Geology Open File 89-1, p. 1-11.

Plate 2. Annotated Map of Quaternary

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

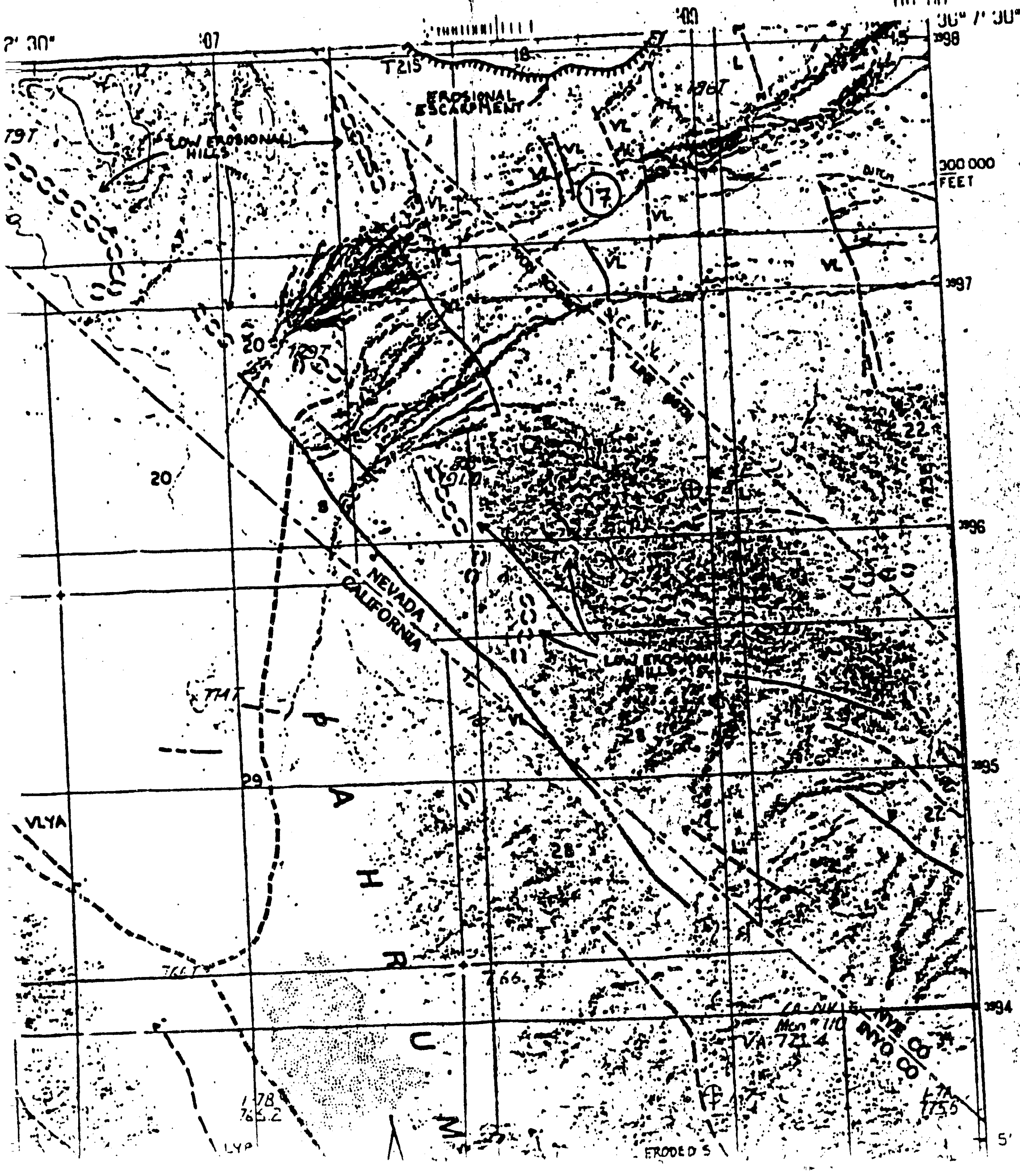


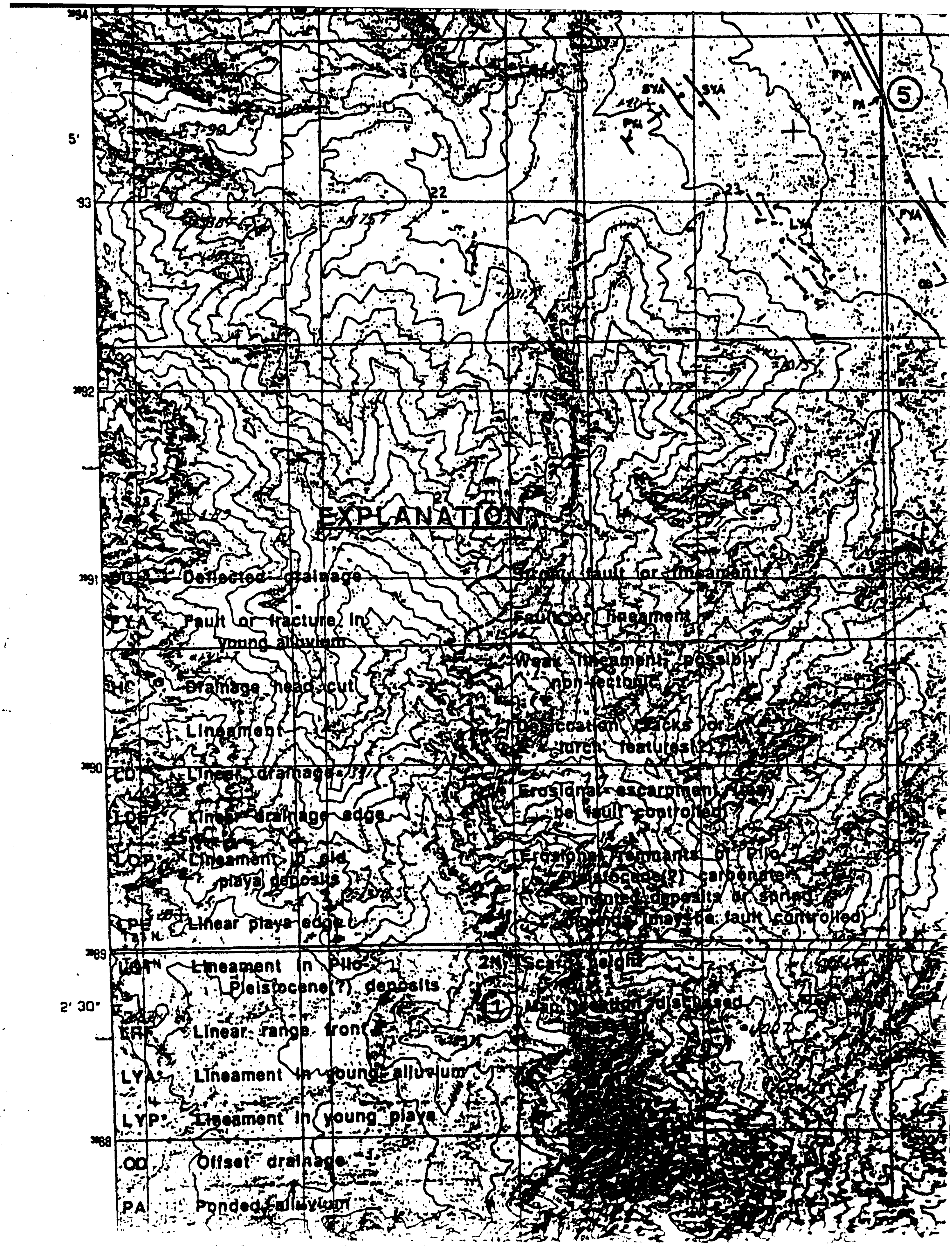
Faults in the Stewart Valley SE, 7.5' Orthophotoquad.

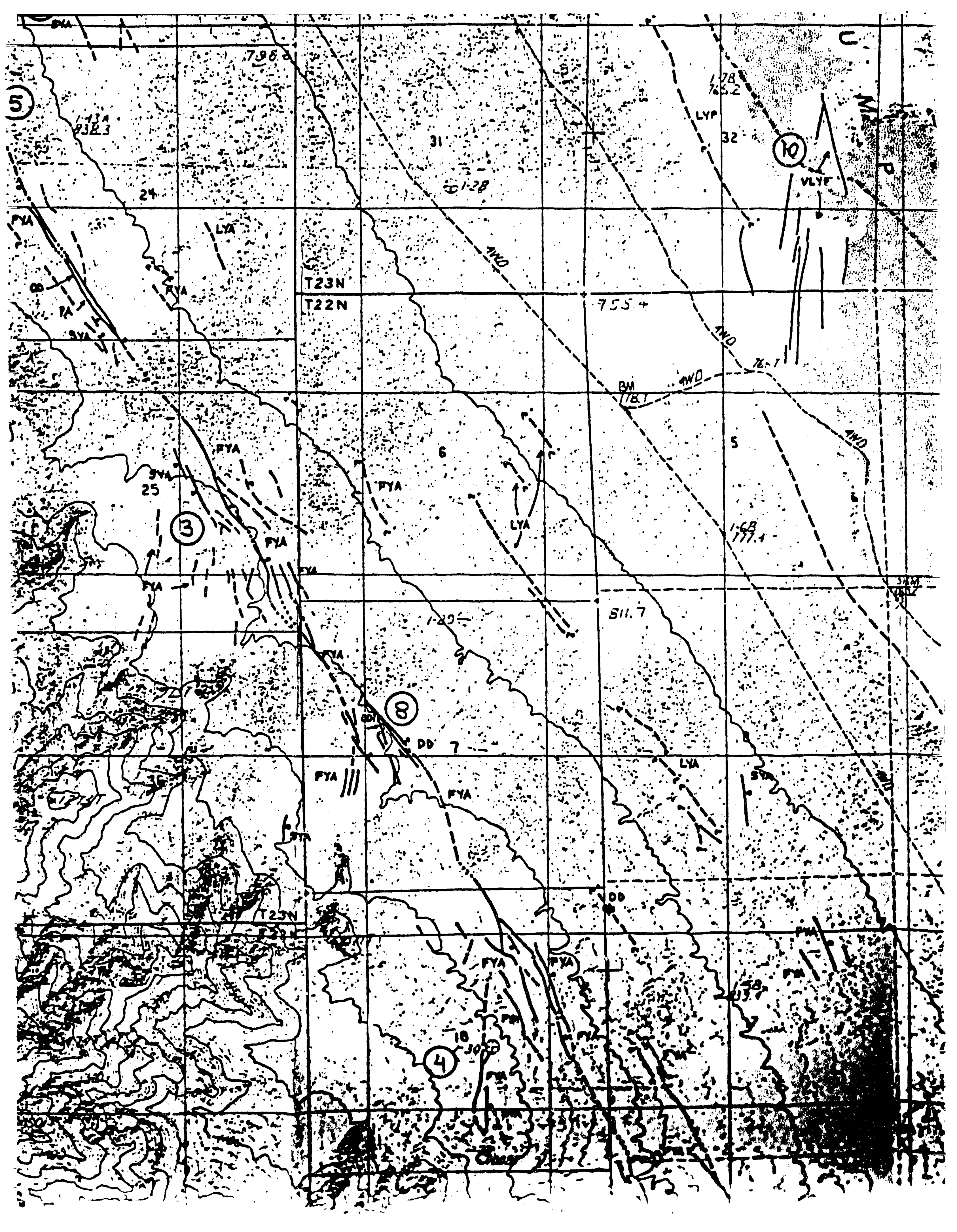


.5' Orthophotoquad.

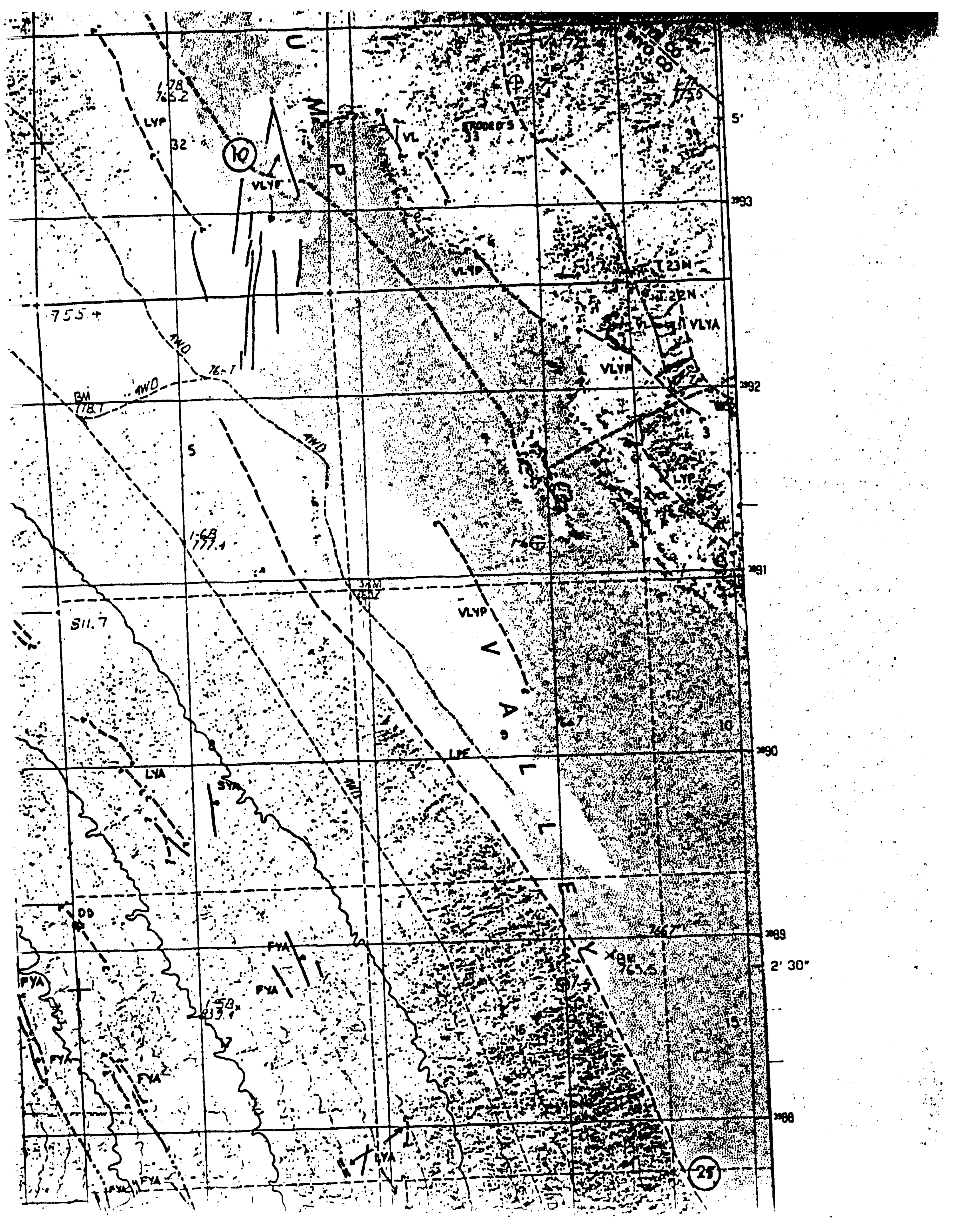
STEWART VALLEY SE ORTHOPHOTOQUAD
CALIFORNIA—NEVADA

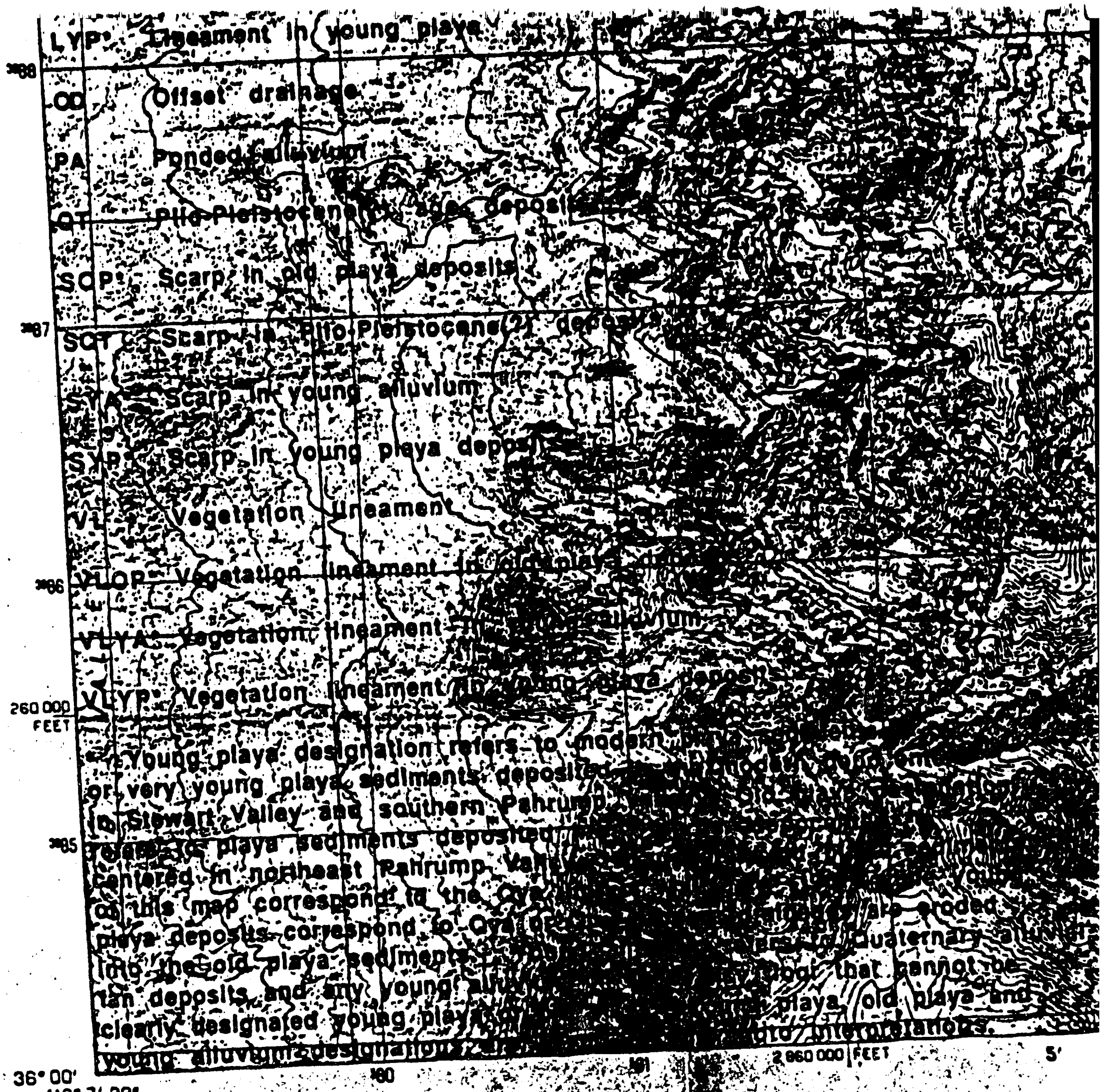



EXPLANATION
Deflected drainage
FYA Fault or fracture in young alluvium
HC Drainage head cut
L Lineament
LD Linear drainage
LDE Linear drainage edge
LOP Lineament in old playa deposits
LPE Linear playa edge
Lineament in Plio-Pleistocene(?) deposits
LRF Linear range front
LYA Lineament in young alluvium
LYP Lineament in young playa
OD Offset drainage
PA Ponded alluvium
Fault or lineament
Weak lineament, possibly non-tectonic
Erosional escarpment, may be fault controlled
Scarp height
Map location discussed
5'
2' 30"
22
23
SYA
PYA
LYA
5



T23N
T22N
4WD
4WD
4WD
4WD
LYP
VLYP
LYA
FYA
SYA
DD
DD
31
32
24
25
6
5
7
18
755.4
811.7


LYP
32
VLYP
VL
ERODED'S
33
5'
3993
VLYP
T23N
T22N
VLYA
VLYP
755.4
4WD
BM
778.7
3992
5
3
LYP
1-6B
777.1
3991
811.7
VLYP
V
A
L
L
E
Y
10
3990
LPE
LYA
SYA
DD
FYA
FYA
3989
BM
765.5
2' 30"
16
15
FYA
3988
25



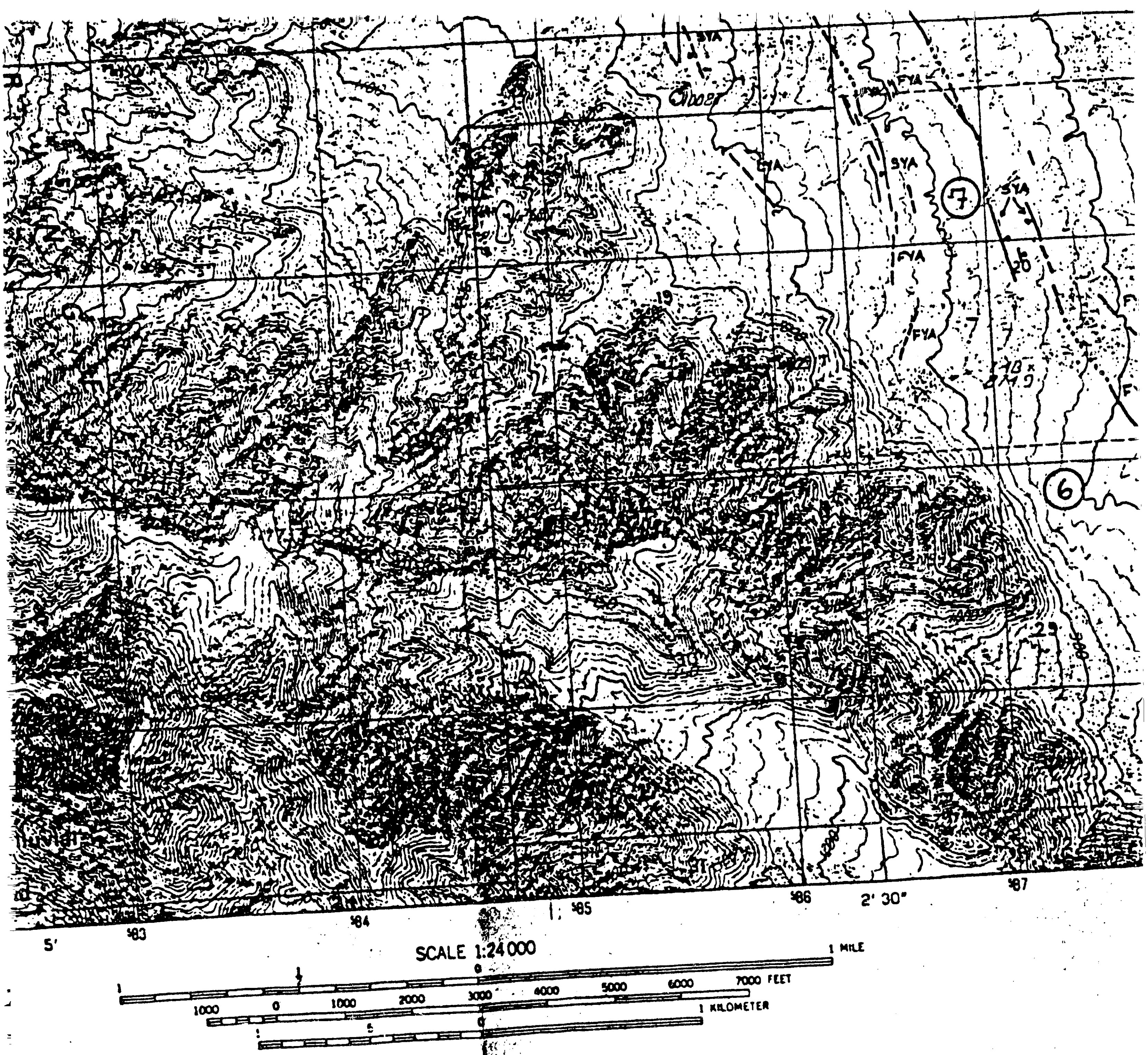
Produced by the Geological Survey
in cooperation with the Soil Conservation Service

Orthophotograph prepared from 1:80 000-scale
aerial photographs taken June 27, 1976

Projection: California coordinate system, zone 4
(Lambert conformal conic)
10,000-foot grids based on California coordinate system, zone 4
and Nevada coordinate system, central zone
1000-meter Universal Transverse Mercator grid ticks,
zone 11. 1927 North American datum

Photoimagery transformed by scanning techniques
which may produce double or mismatched images;
use the mean of image positions for map point.

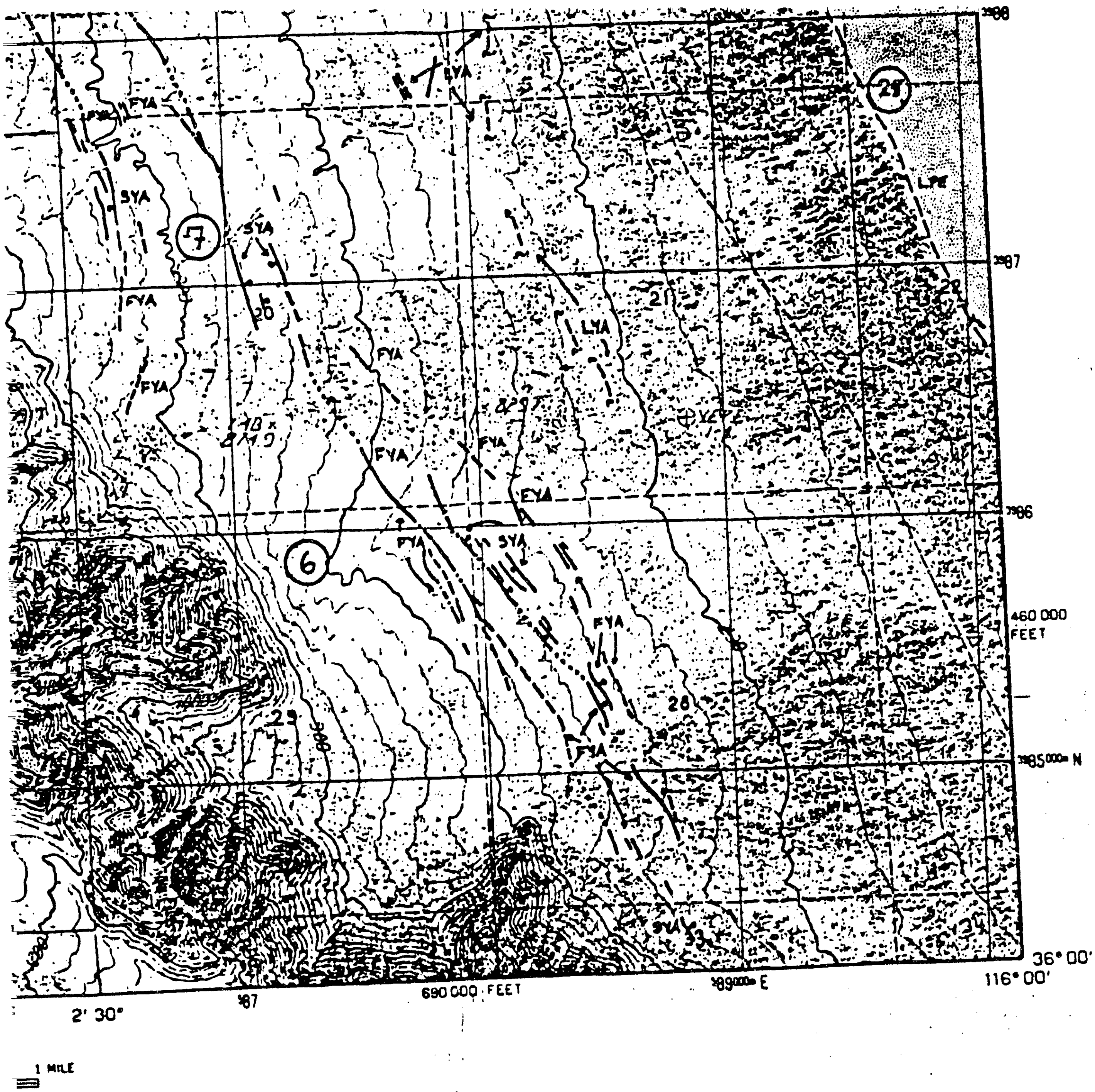
NORTH



by

Joanne L. Hoffard

1990



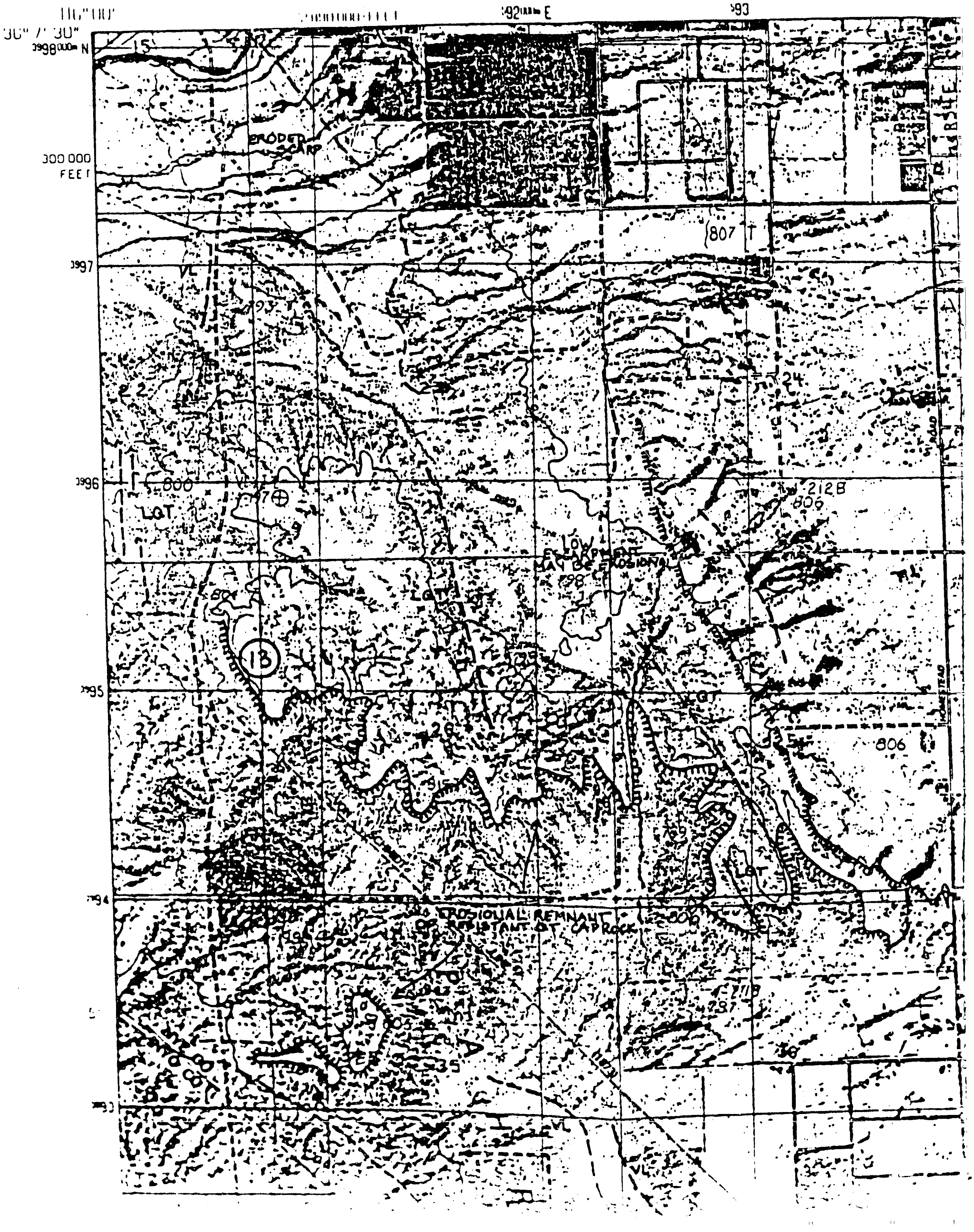
STEWART VALLEY SE, CALIF.—NEV.
N3600—W11600/7.5

1976

ADVANCE PRINT

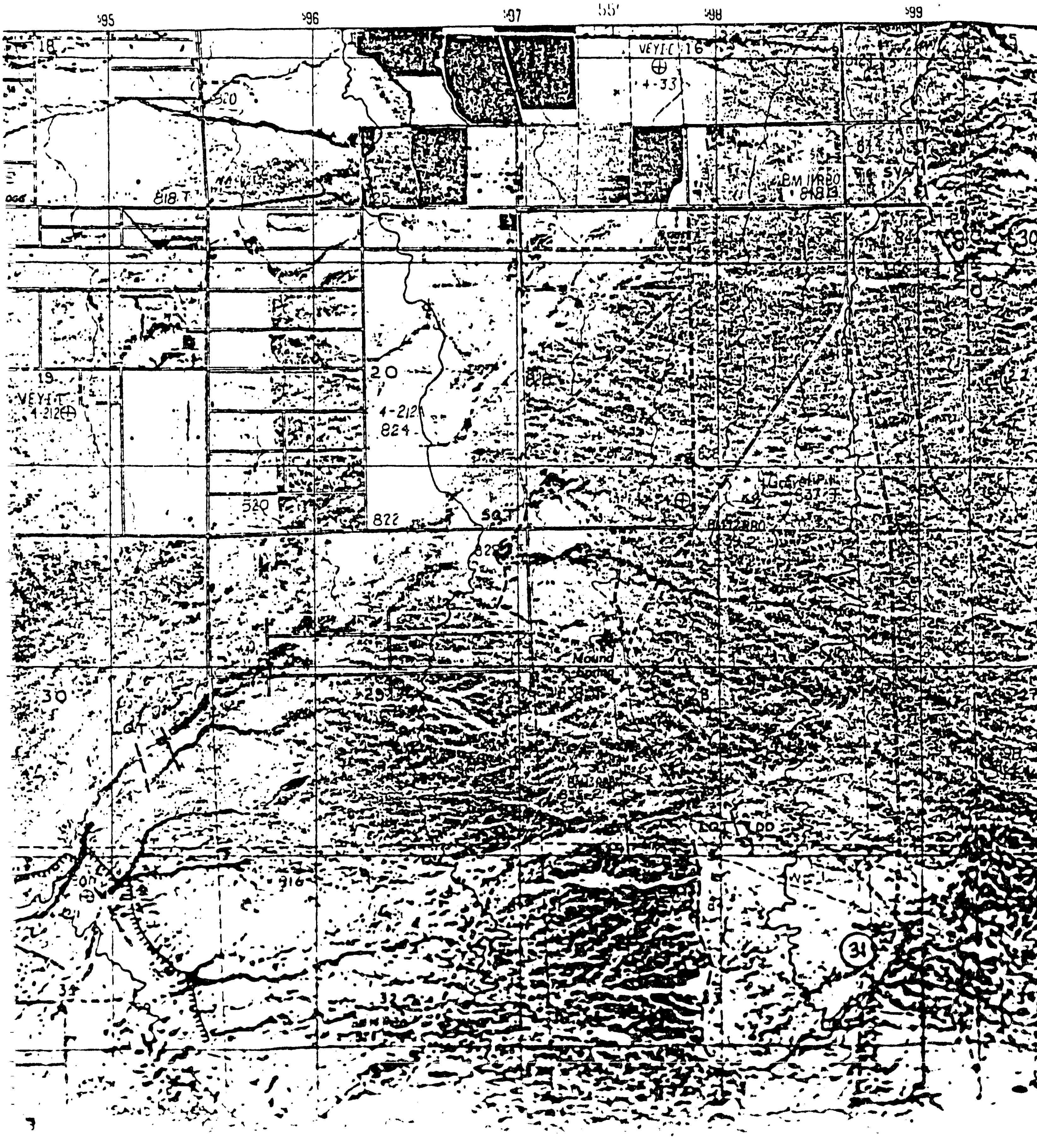
Plate 3. Annotated Map of Quat

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY



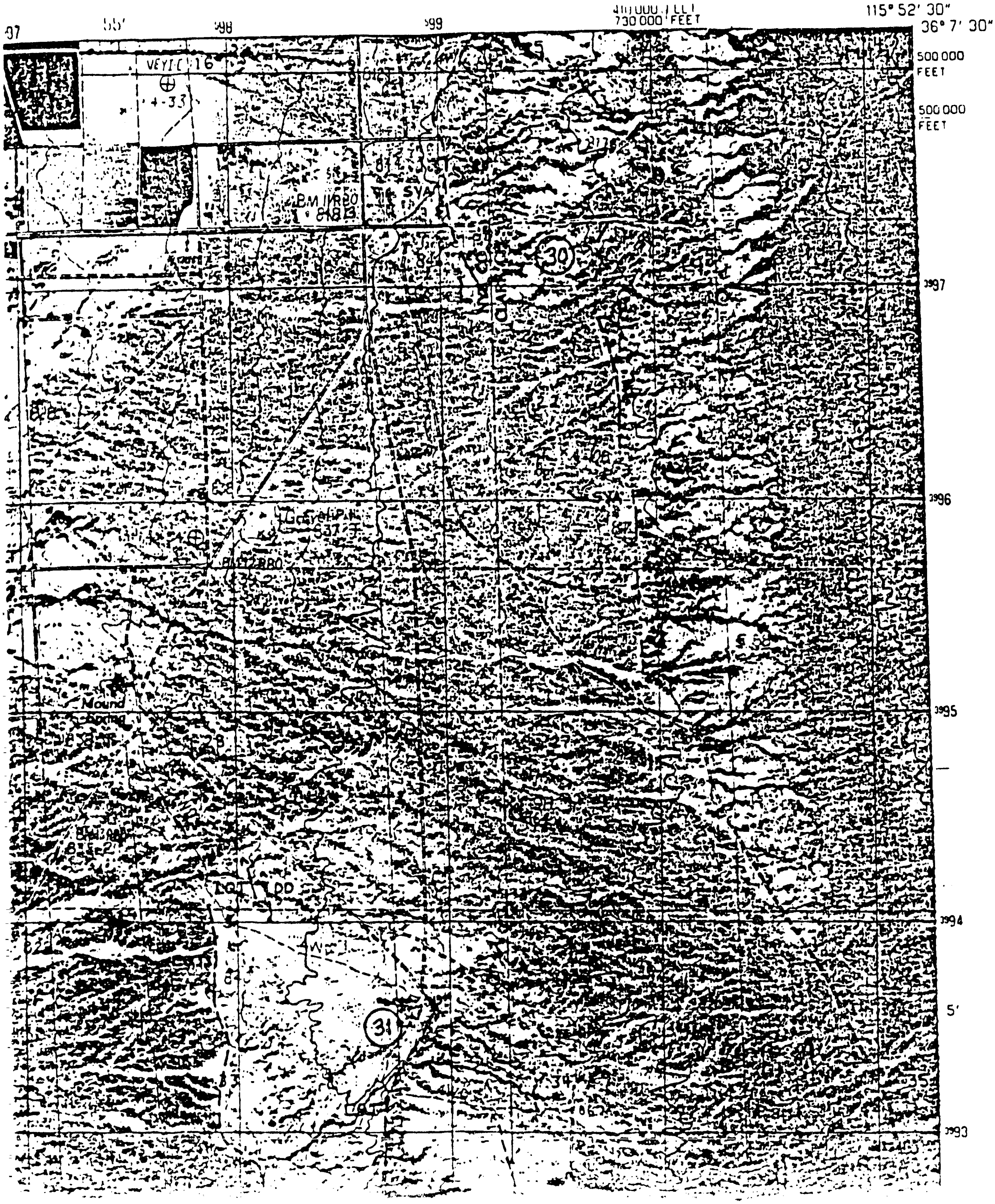
/ Faults in the Pahrump SW, 7.5' Orthophotoquad.

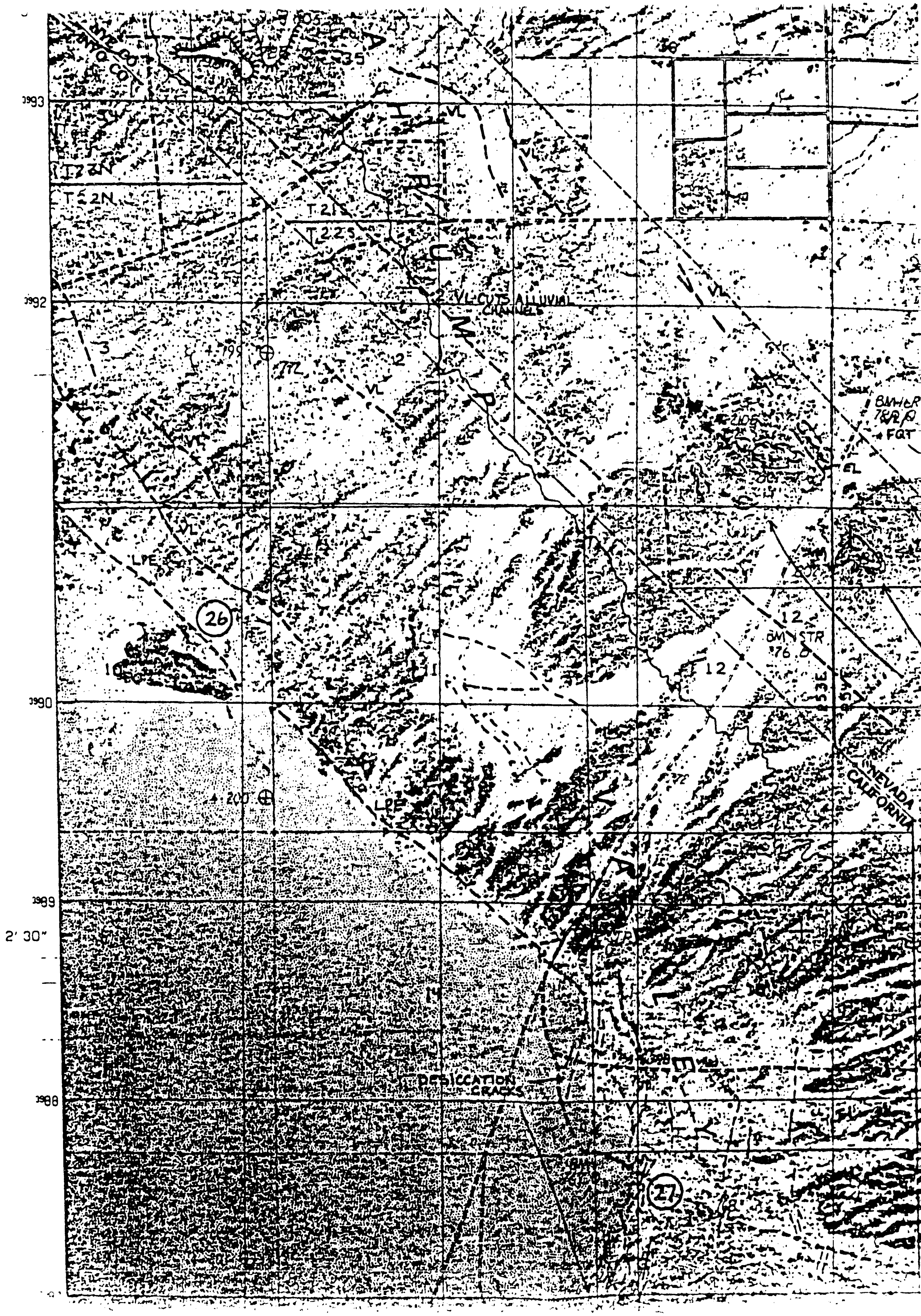
PAH

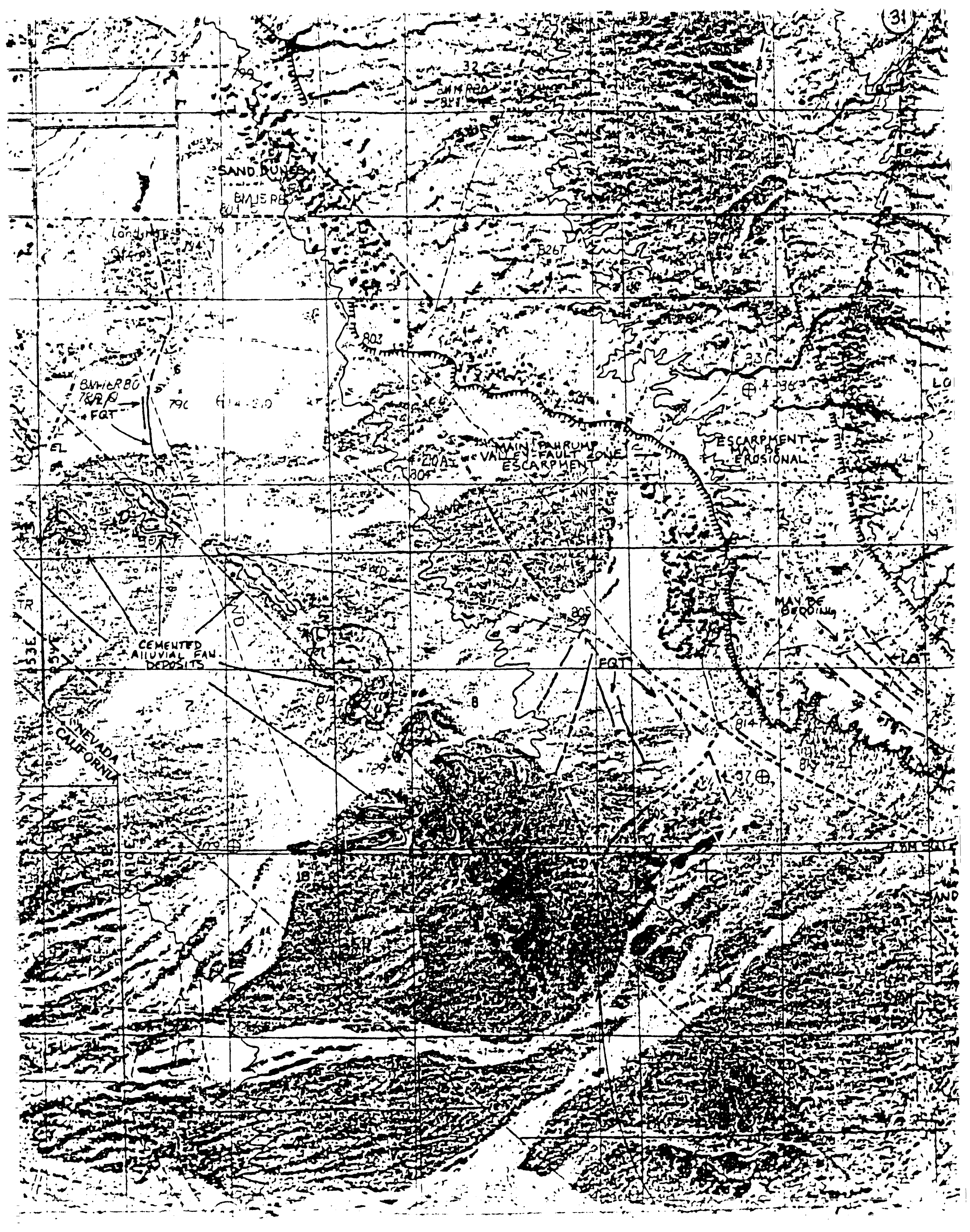


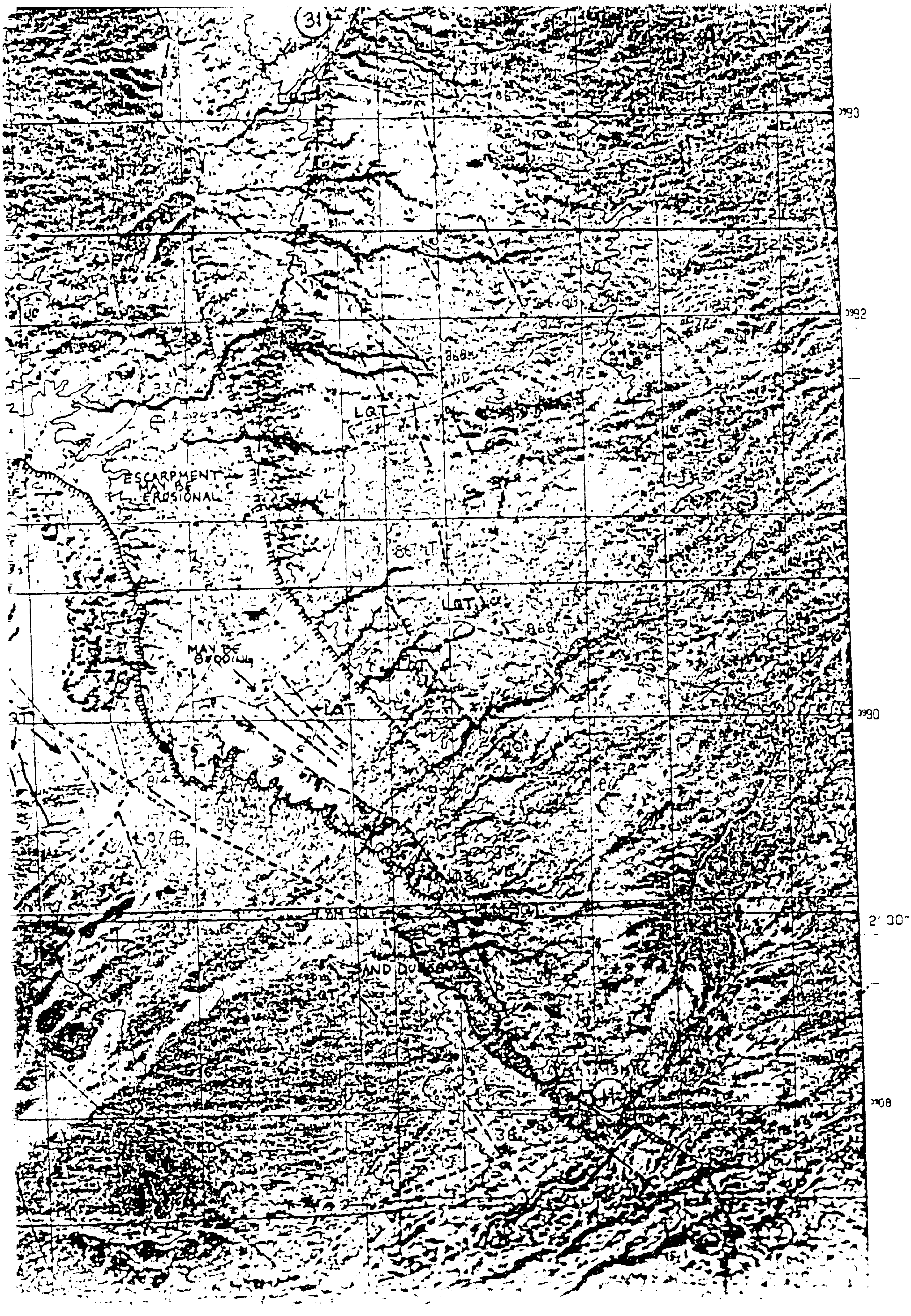
'.5' Orthophotoquad.

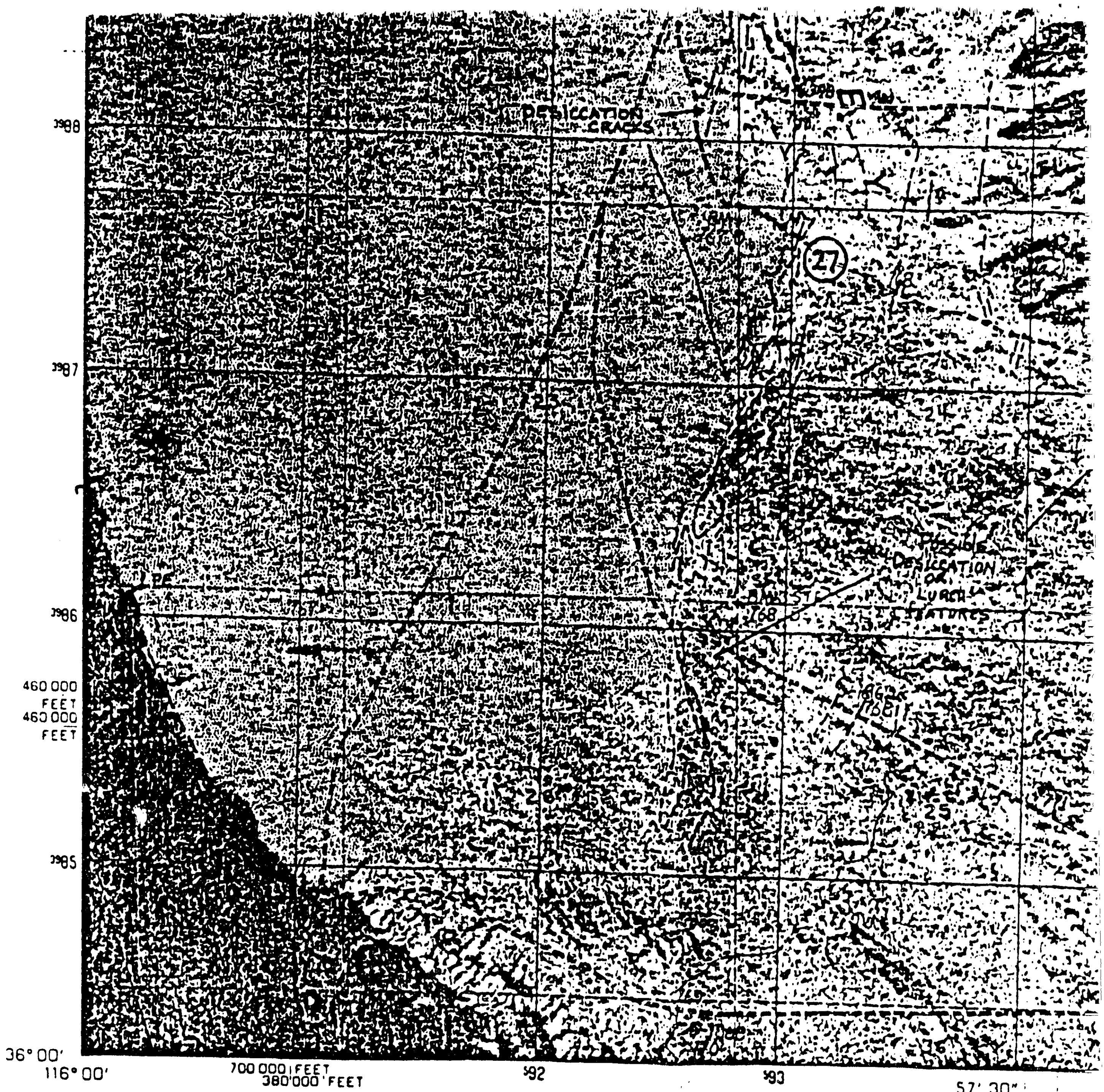
PAHRUMP SW ORTHOPHOTOQUAD
NEVADA—CALIFORNIA




3993
T 22 N
T 21
T 22 S
3992
VL CUTS ALLUVIAL CHANNELS
VL
LPE
26
12
BM STR
3990
200
3989
2' 30"
NEVADA
CALIFORNIA
DESICCATION CRACKS
3988
27


SAND DUNES
FQT
MAIN PAHRUMP VALLEY FAULT ZONE ESCARPMENT
ESCARPMENT MAY BE EROSIONAL
MAY BE BEDDING
CEMENTED ALLUVIAL FAN DEPOSITS
FQT
NEVADA
CALIFORNIA
32
33
34
803
805
8267


31
ESCARPMENT
MAY BE
EROSIONAL
MAY BE
LQT
LQT
868
814
2' 30"

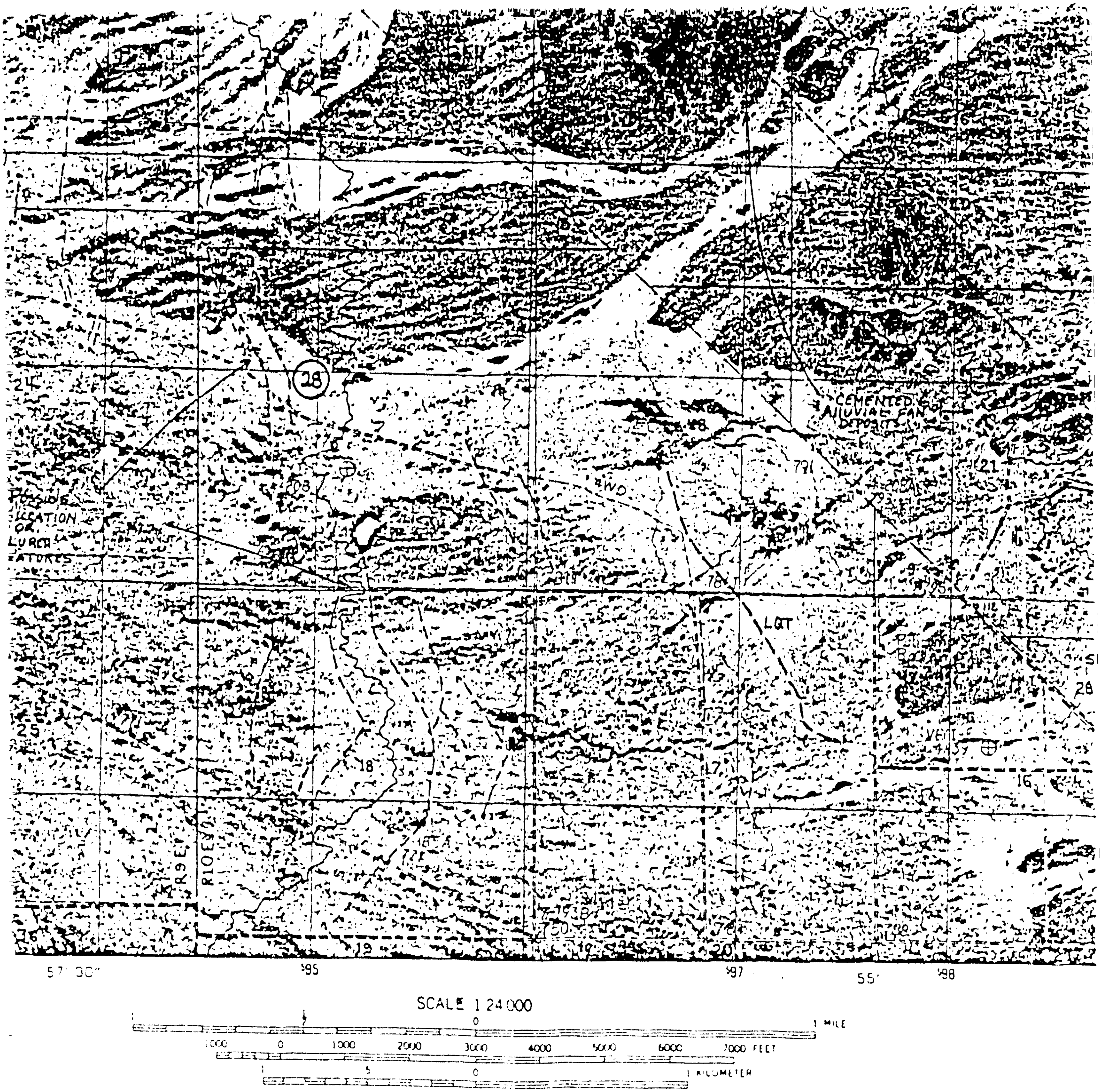


Produced by the Geological Survey
in cooperation with the Soil Conservation Service

Orthophotograph prepared from 1:80 000-scale
aerial photographs taken June 4, 1976

Projection: Nevada coordinate system, central zone
(transverse Mercator)
10,000-foot grids based on Nevada coordinate system, central zone
and California coordinate system, zone 4,
and Nevada coordinate system east zone
1000-meter Universal Transverse Mercator grid ticks,
zone 11. 1927 North American datum

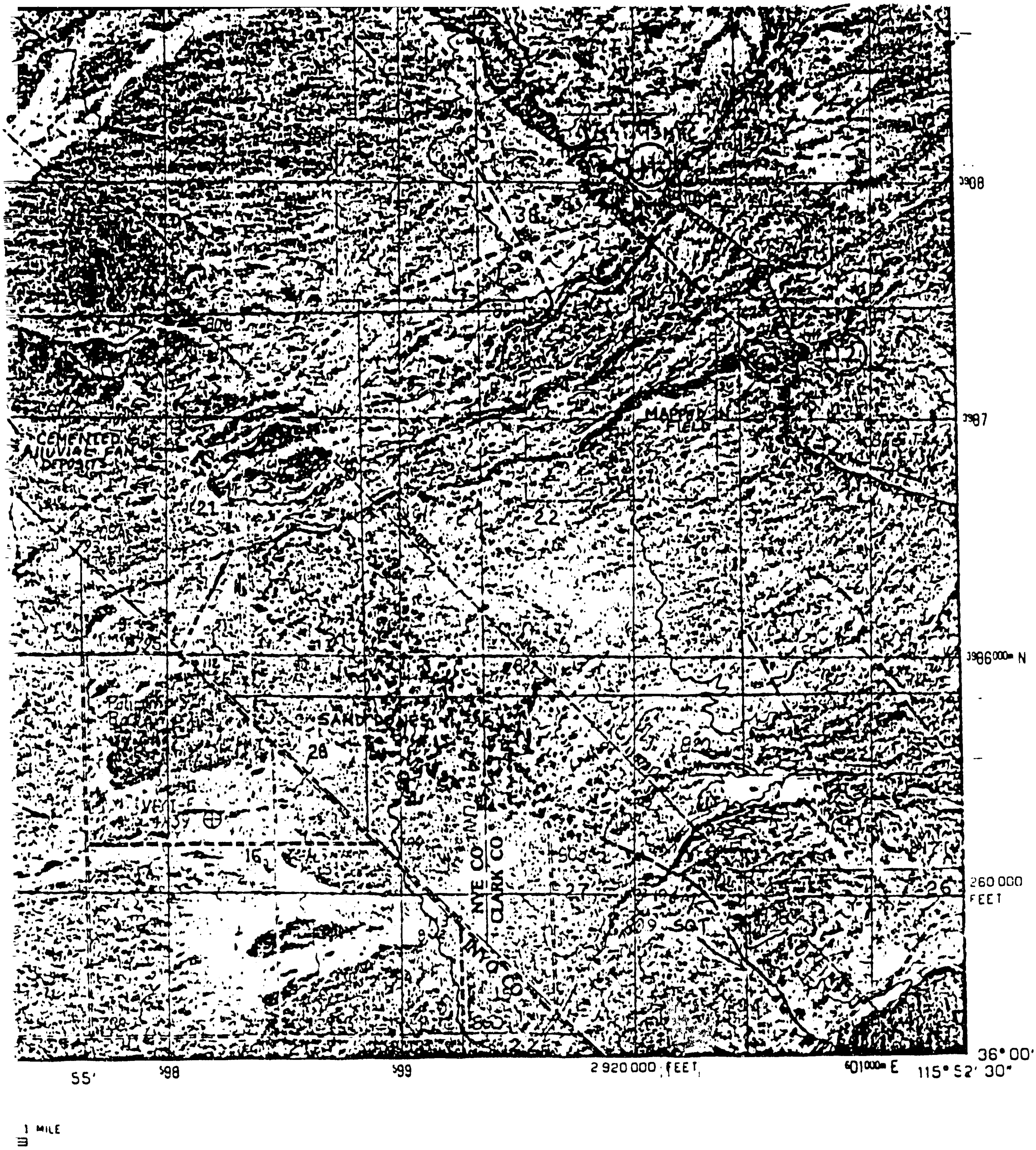
Photoimagery transformed by scanning techniques
which may produce double or mismatched images,
use the mean of image positions for map point.



by

Joanne L. Hoffard

1990



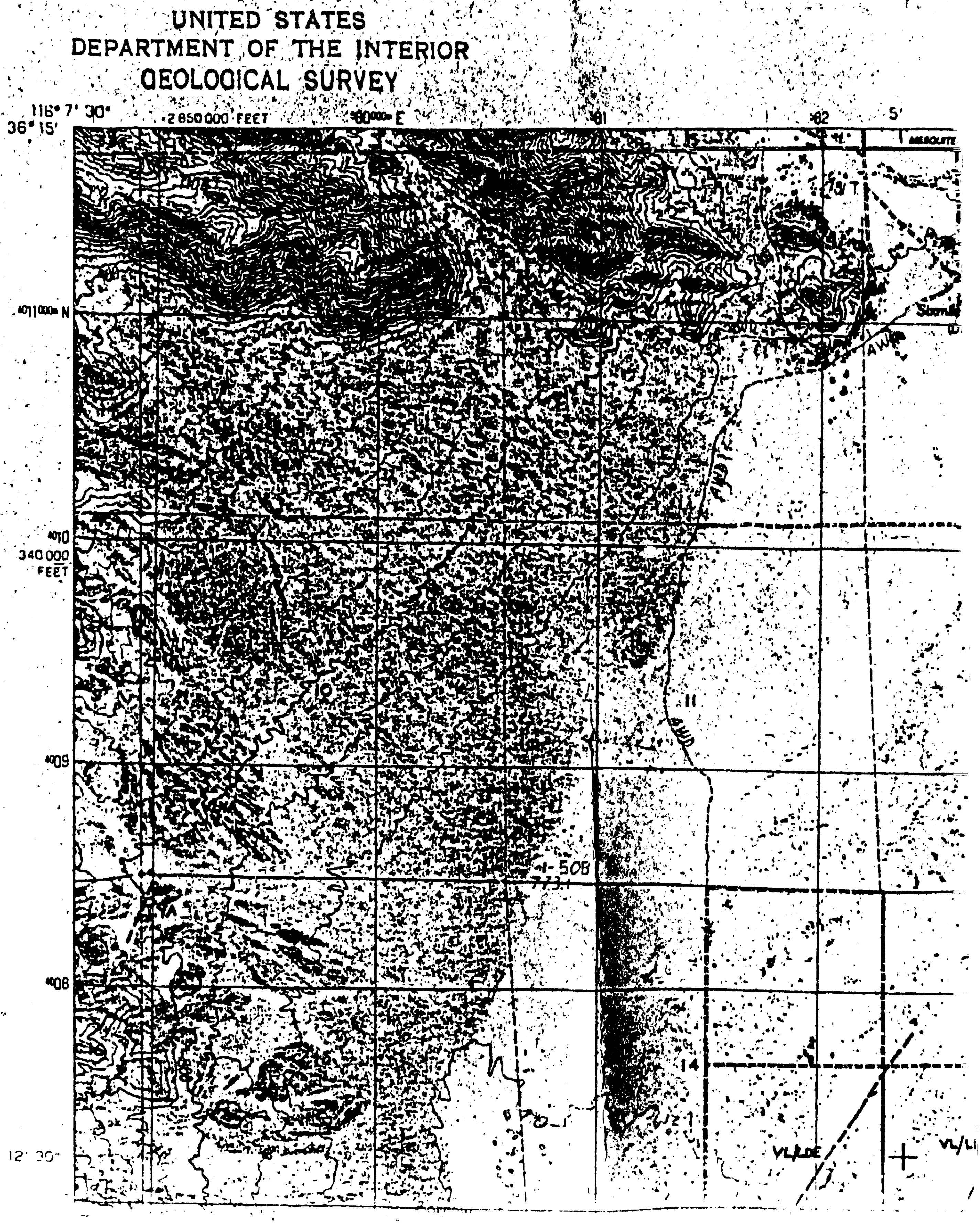
PAHRUMP SW, NEV.—CALIF.

N3600—W11552.5/7.5

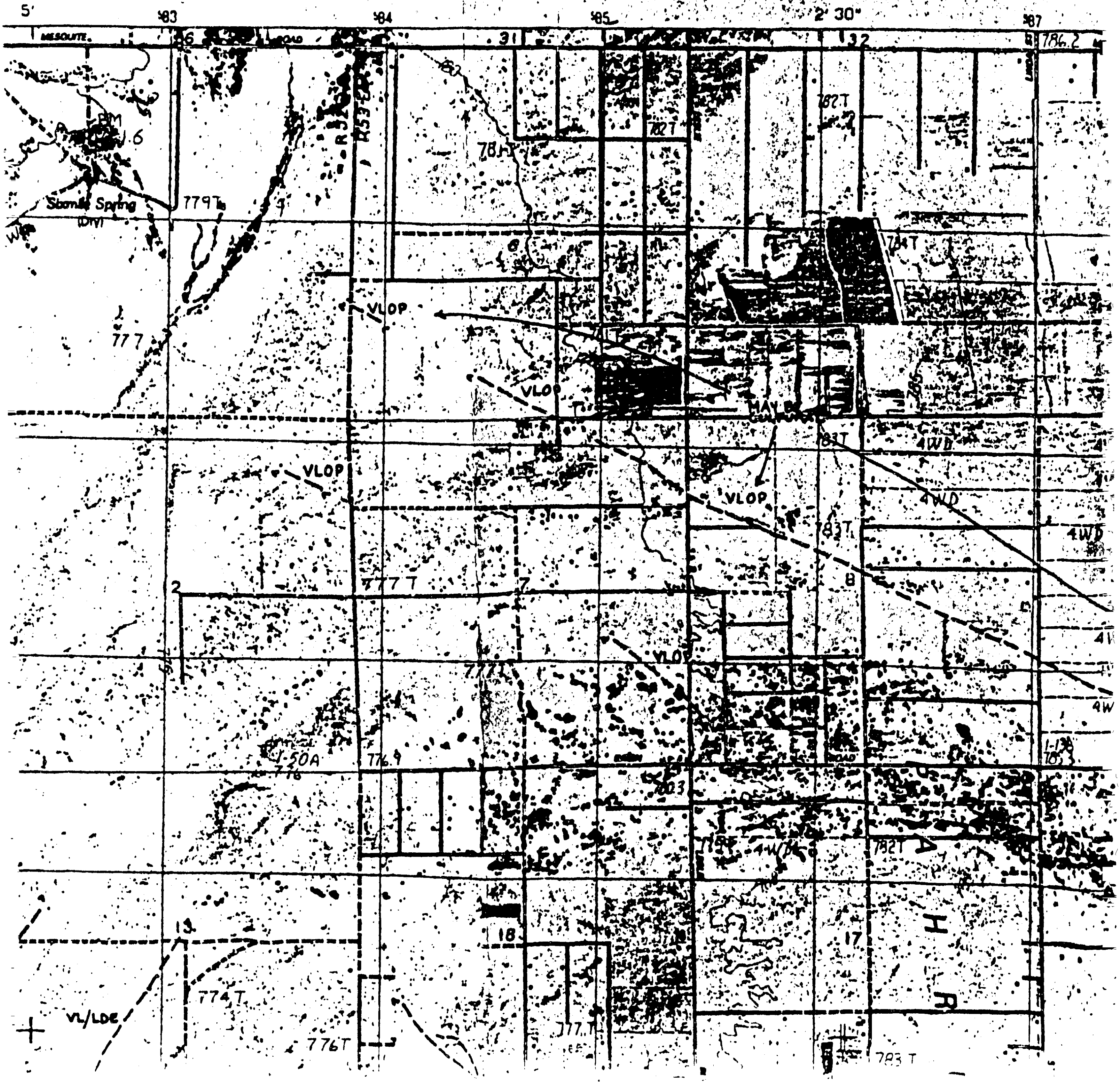
1976

ADVANCE PRINT

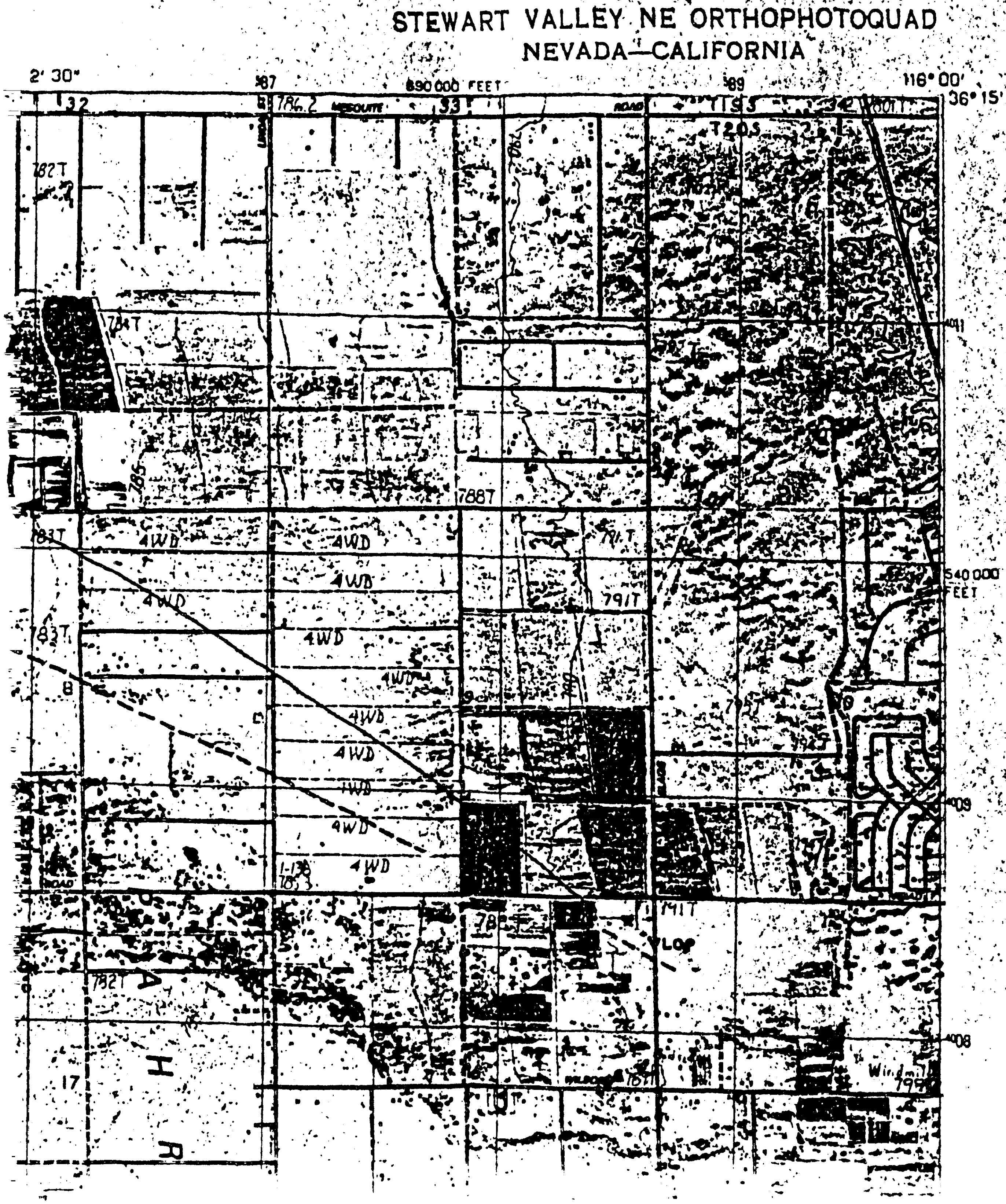
Plate 4. Annotated Map of Qua

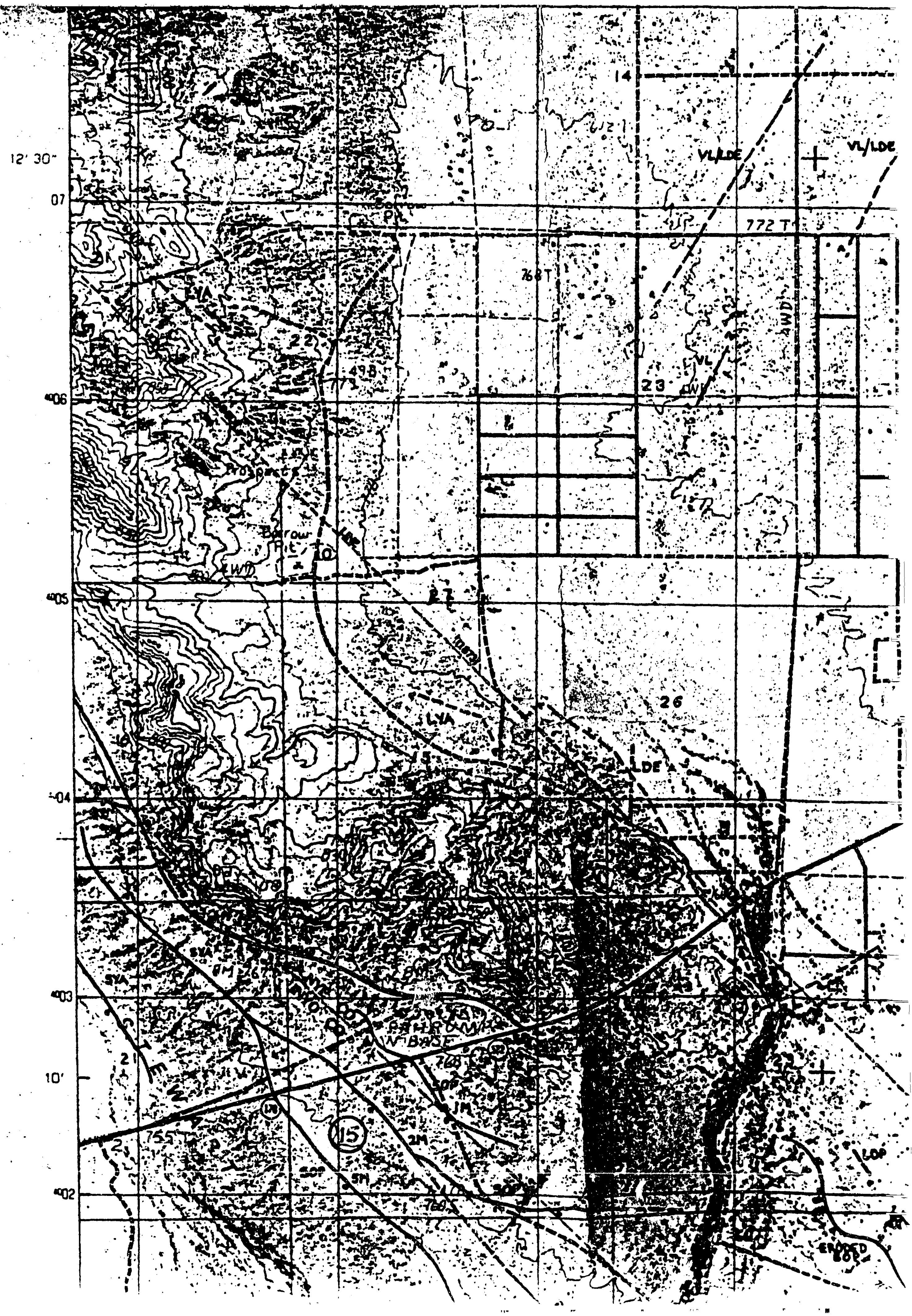


Quaternary Faults in the Stewart Valley NE, 7.5' Orthophotoq

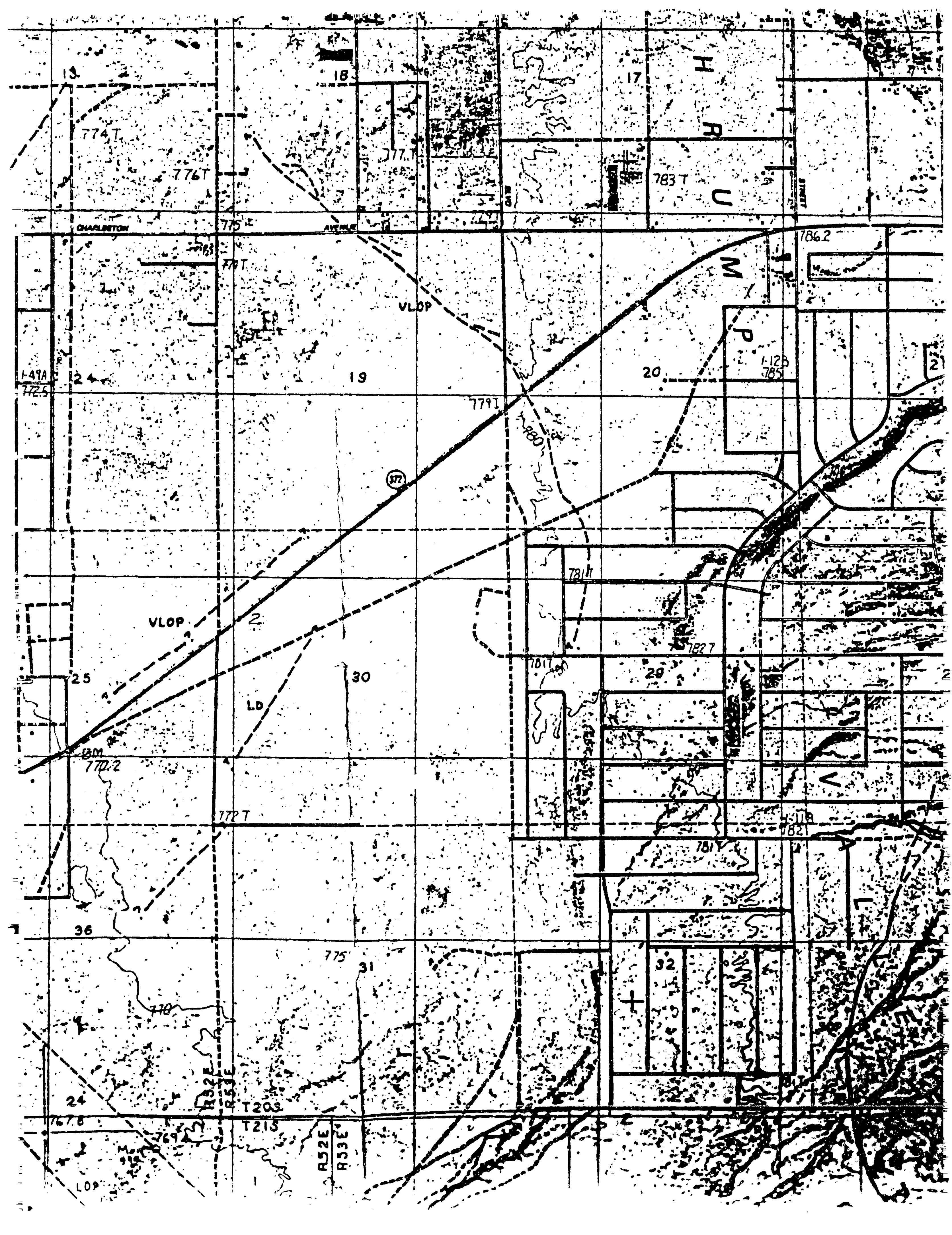


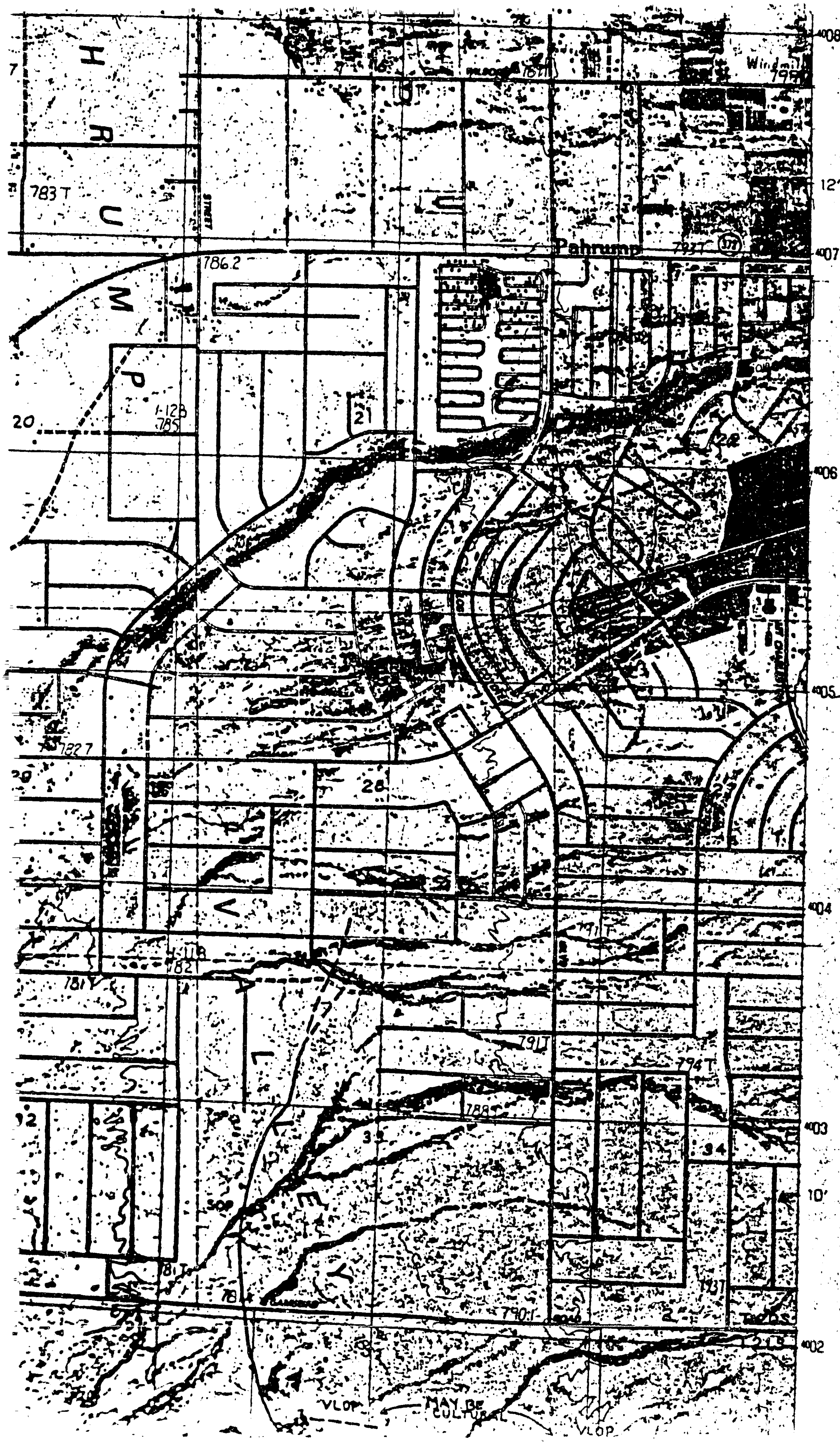
, 7.5' Orthophotoquad.



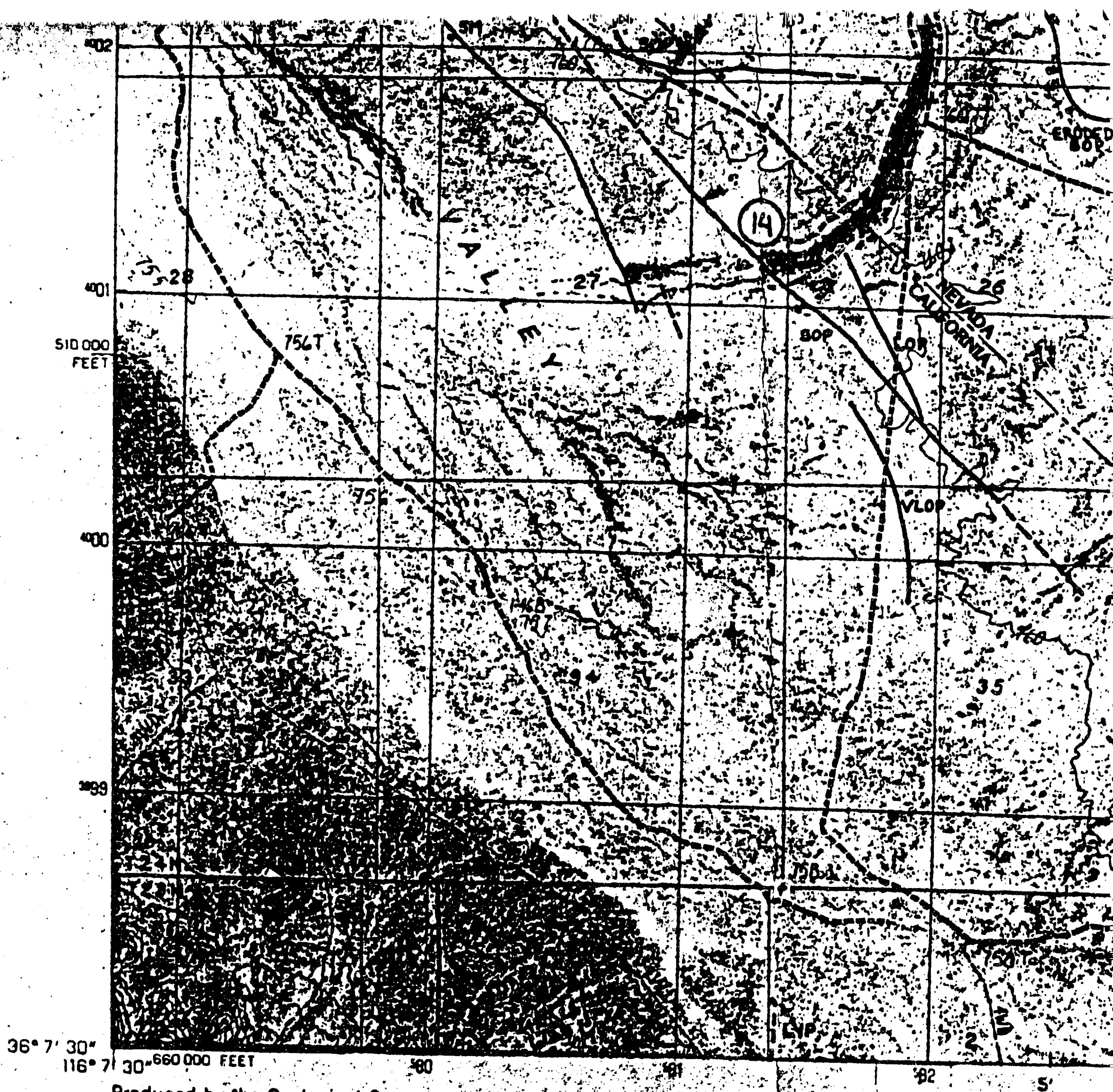


12' 30"
07
4006
4005
4004
4003
10'
4002
14
VL/LDE
VL/LDE
772 T
768 T
22
23
26
LDE
SLYA
Borrow Pit
Prospect
AWD
755
768
769
15
LOP


13
18
17
774T
776T
777T
783T
CHARLESTON
AVENUE
775
786.2
VLOP
1-49A
772.5
24
19
20
1-128
785
779I
780
372
781T
VLOP
2
782T
781T
25
30
29
LD
BM
770.2
772T
1-118
782
36
775
31
32
770
24
767.8
T20S
T21S
R52E
R53E
769
LOP



Windmill
12' 30"
Pahrump
4008
4007
4006
4005
4004
4003
4002
10'
783 T
786.2
20
21
28
29
782.7
781
791 T
794 T
788
34
793 T
790 T
VLOP
MAY BE CULTURAL
VLOP



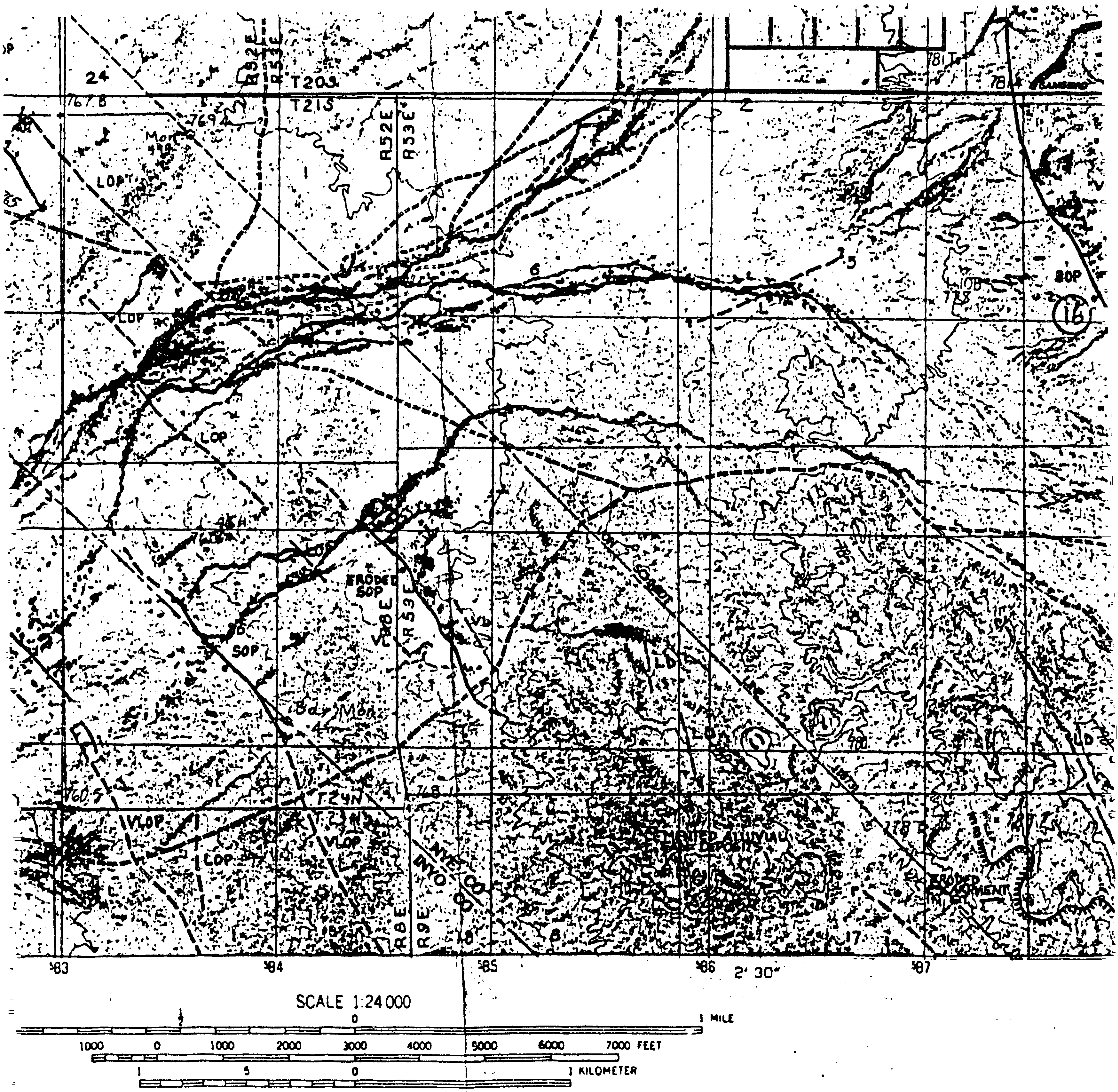
Produced by the Geological Survey
in cooperation with the Soil Conservation Service

Orthophotograph prepared from 1:80 000-scale aerial photographs taken June 4, 1976

Projection: Nevada coordinate system, central zone (transverse Mercator)
10,000-foot grids based on Nevada coordinate system, central zone and California coordinate system, zone 4
1000-meter Universal Transverse Mercator grid ticks, zone 11. 1927 North American datum

Photoimagery transformed by scanning techniques which may produce double or mismatched images; use the mean of image positions for map point.

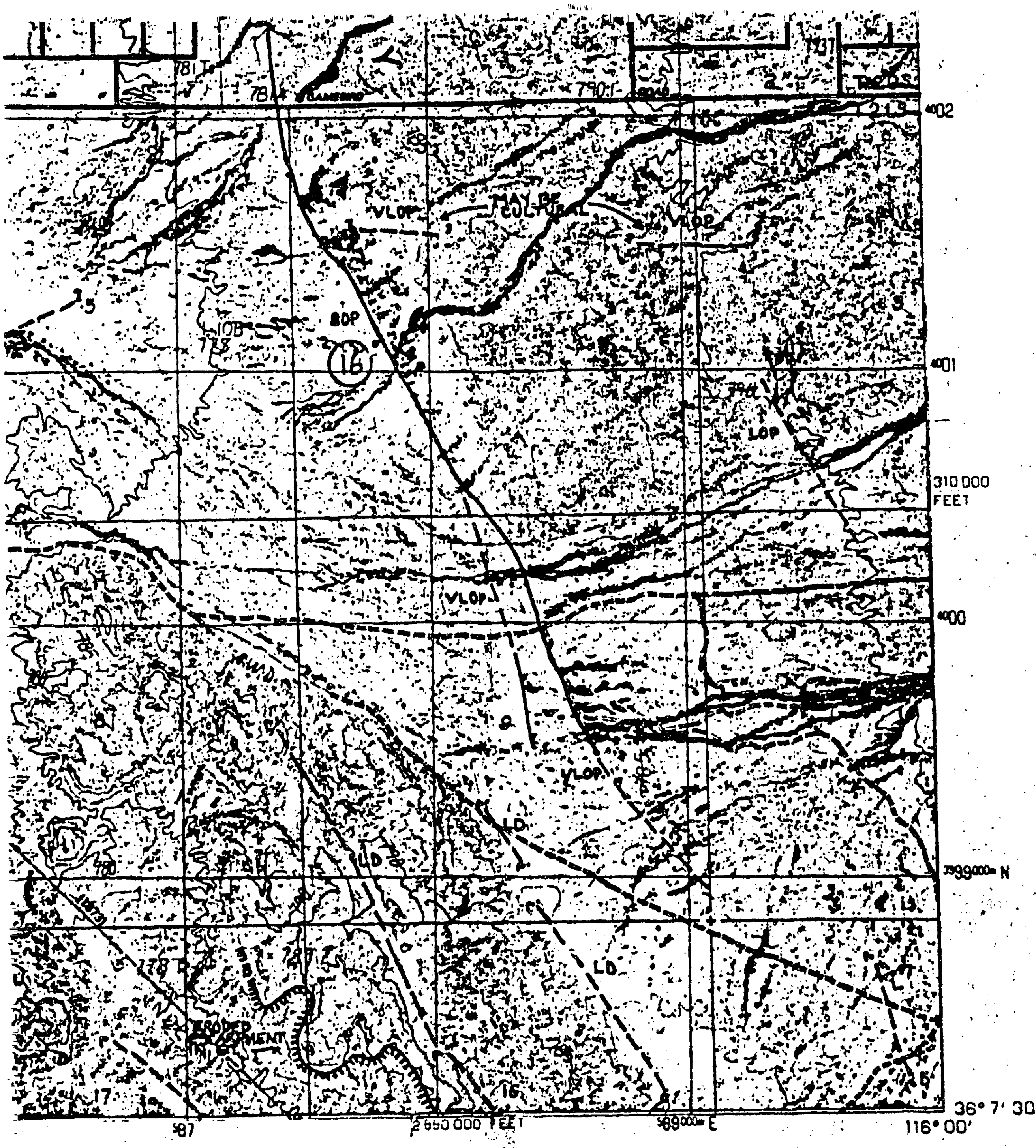
NORTH



by

Joanne L. Hoffard

1990



STEWART VALLEY NE, NEV.—CALIF.

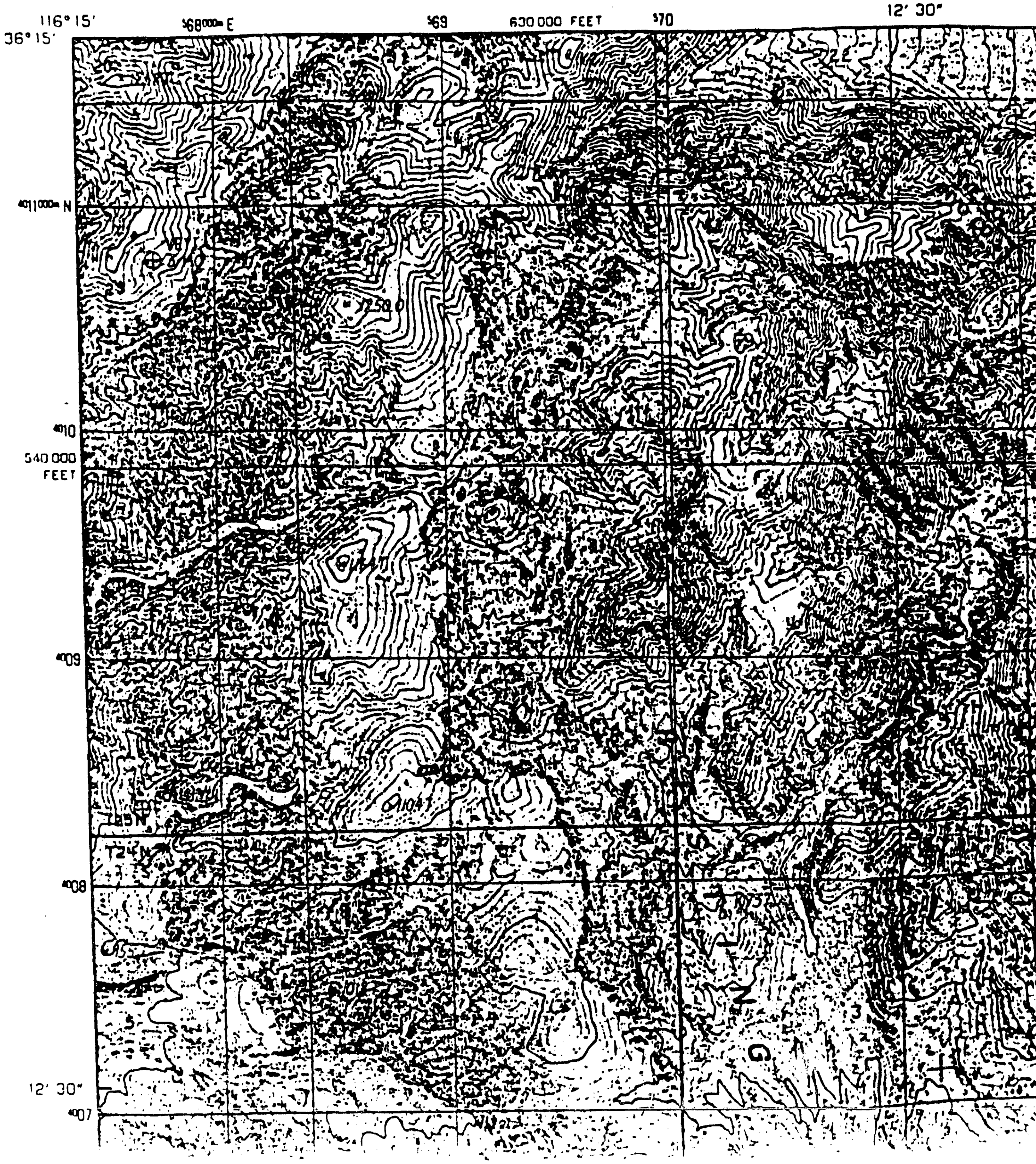
N3607.5—W11600/7.5

1975

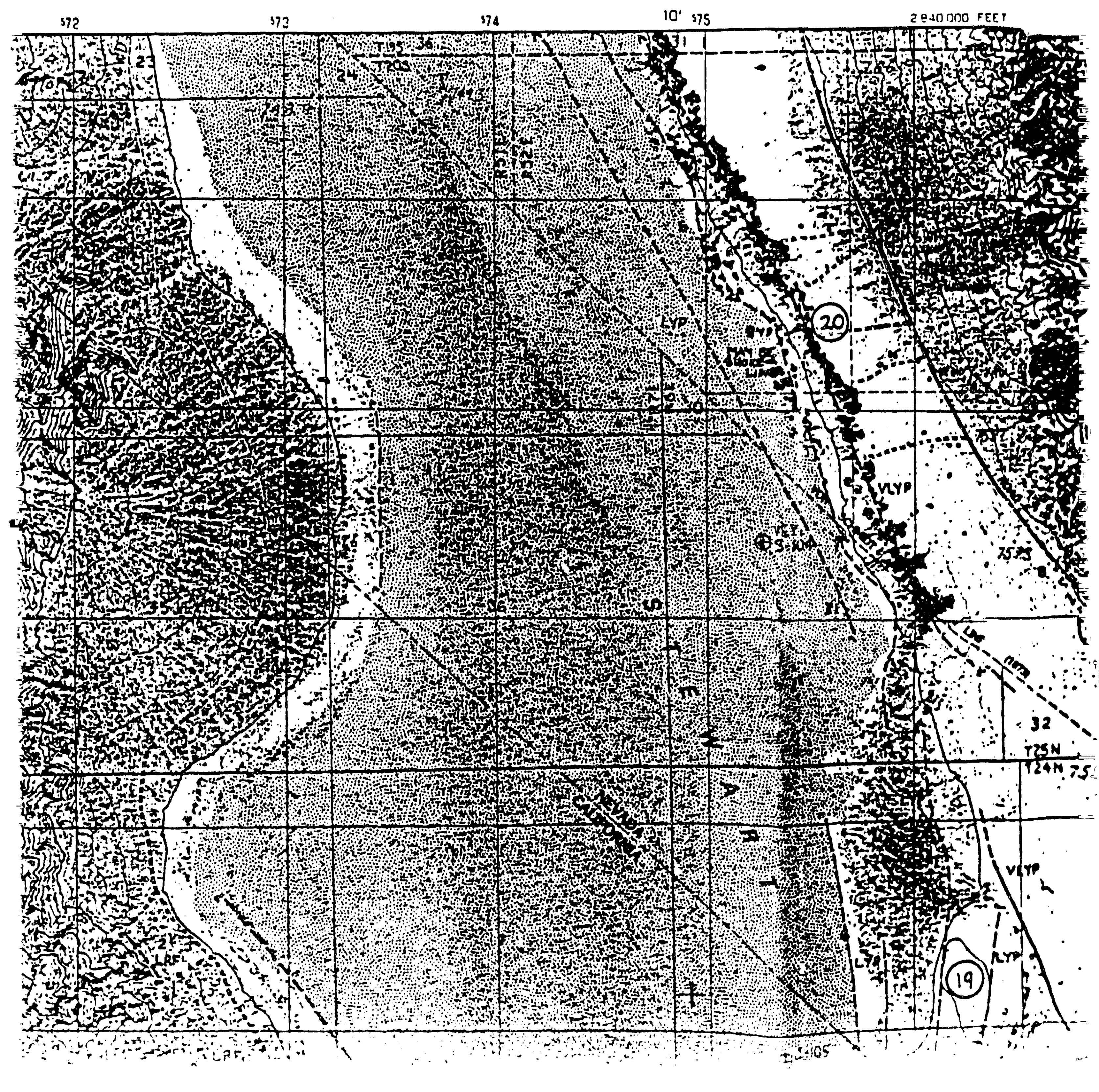
ADVANCE PRINT

Plate 5. Annotated Map of Quat

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

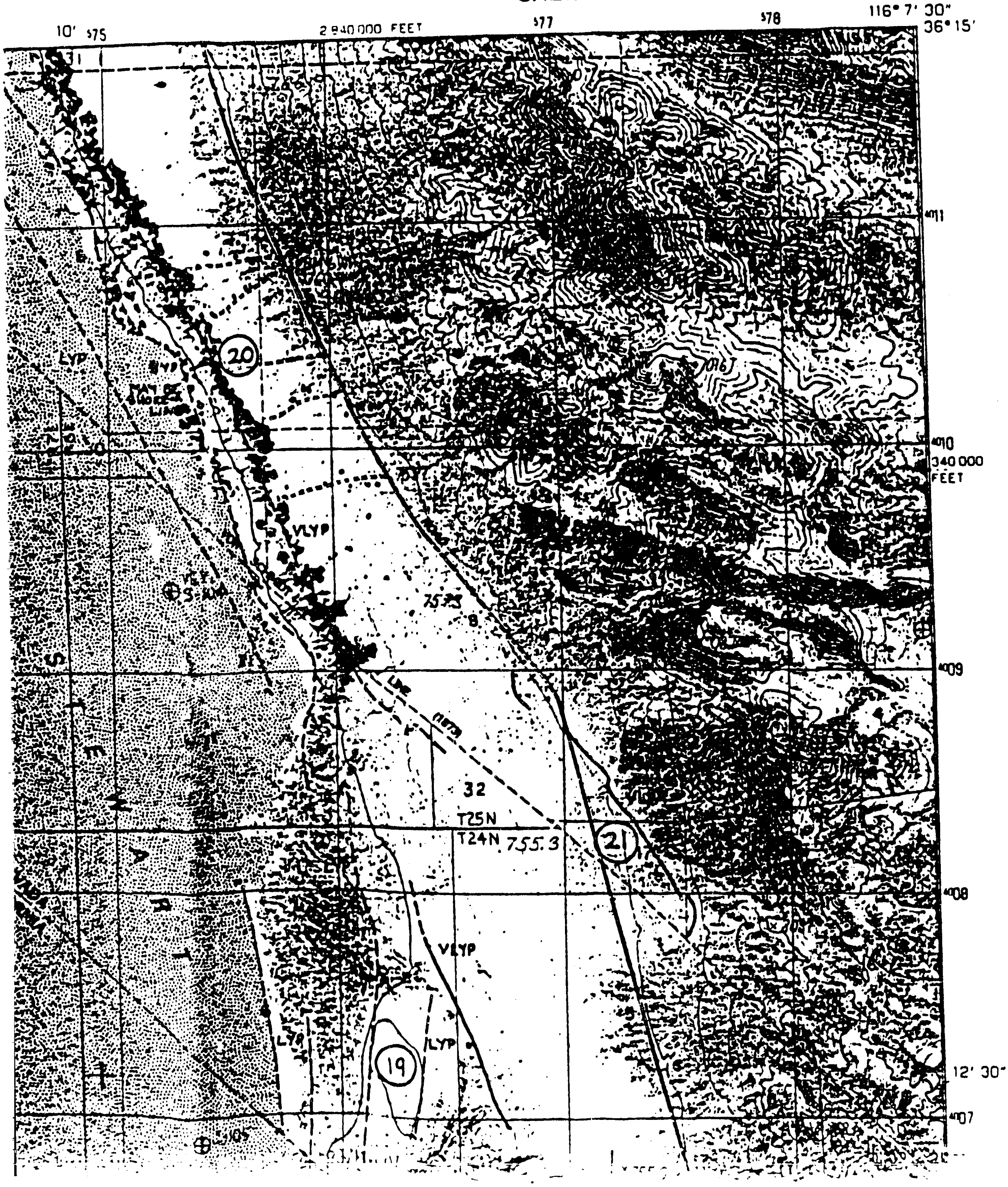


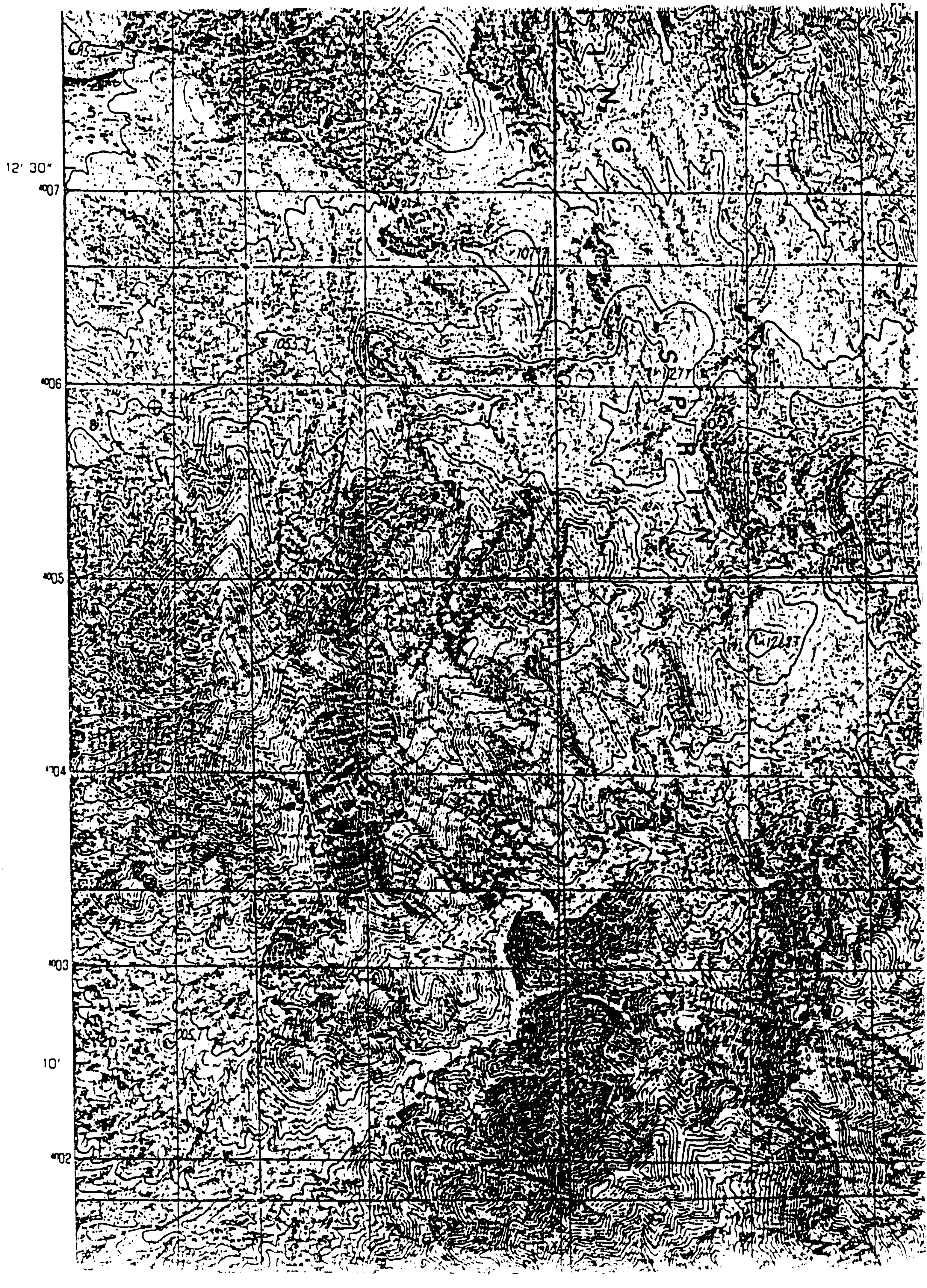
ernary Faults in the Stewart Valley NW, 7.5' Orthophotoquad.

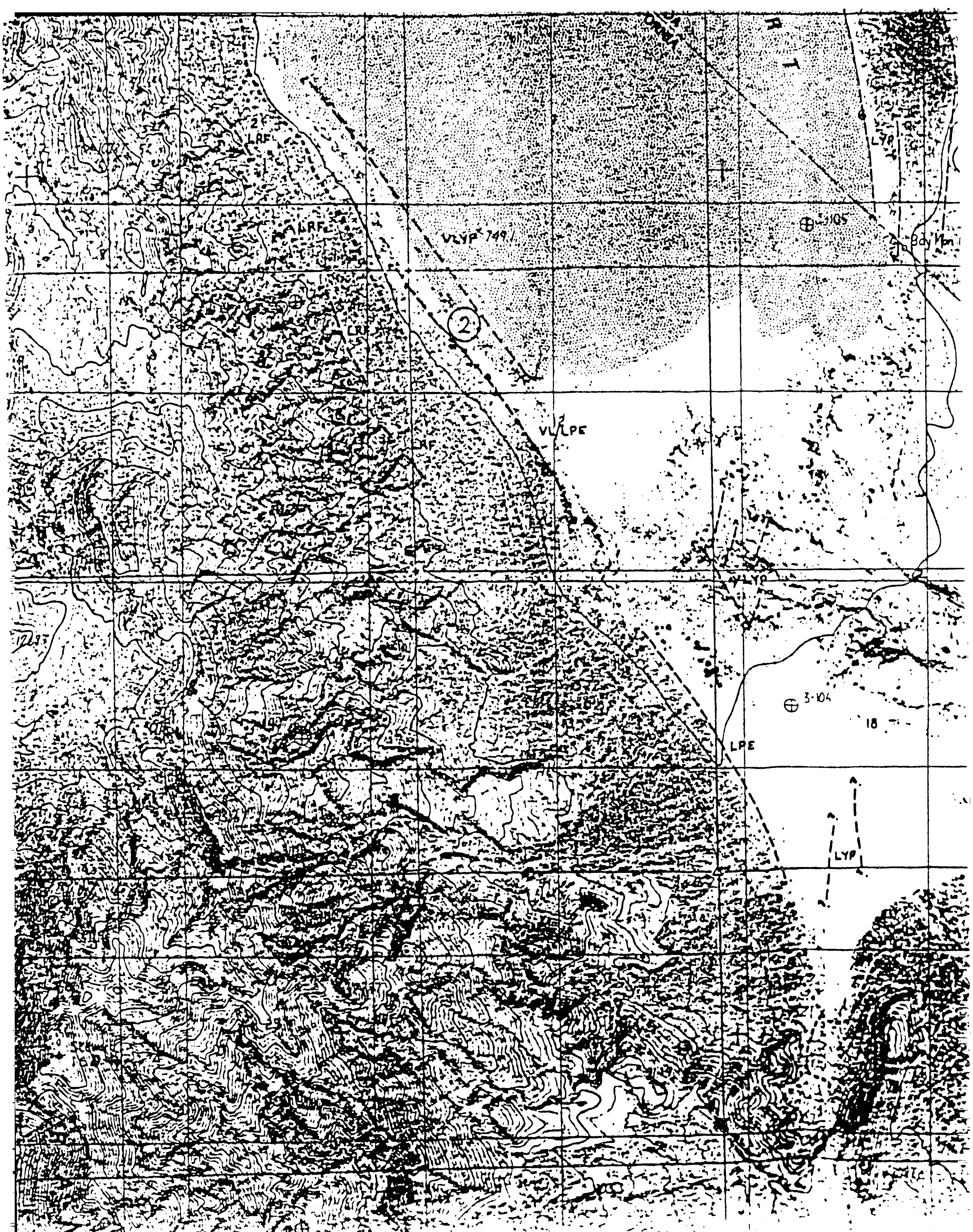


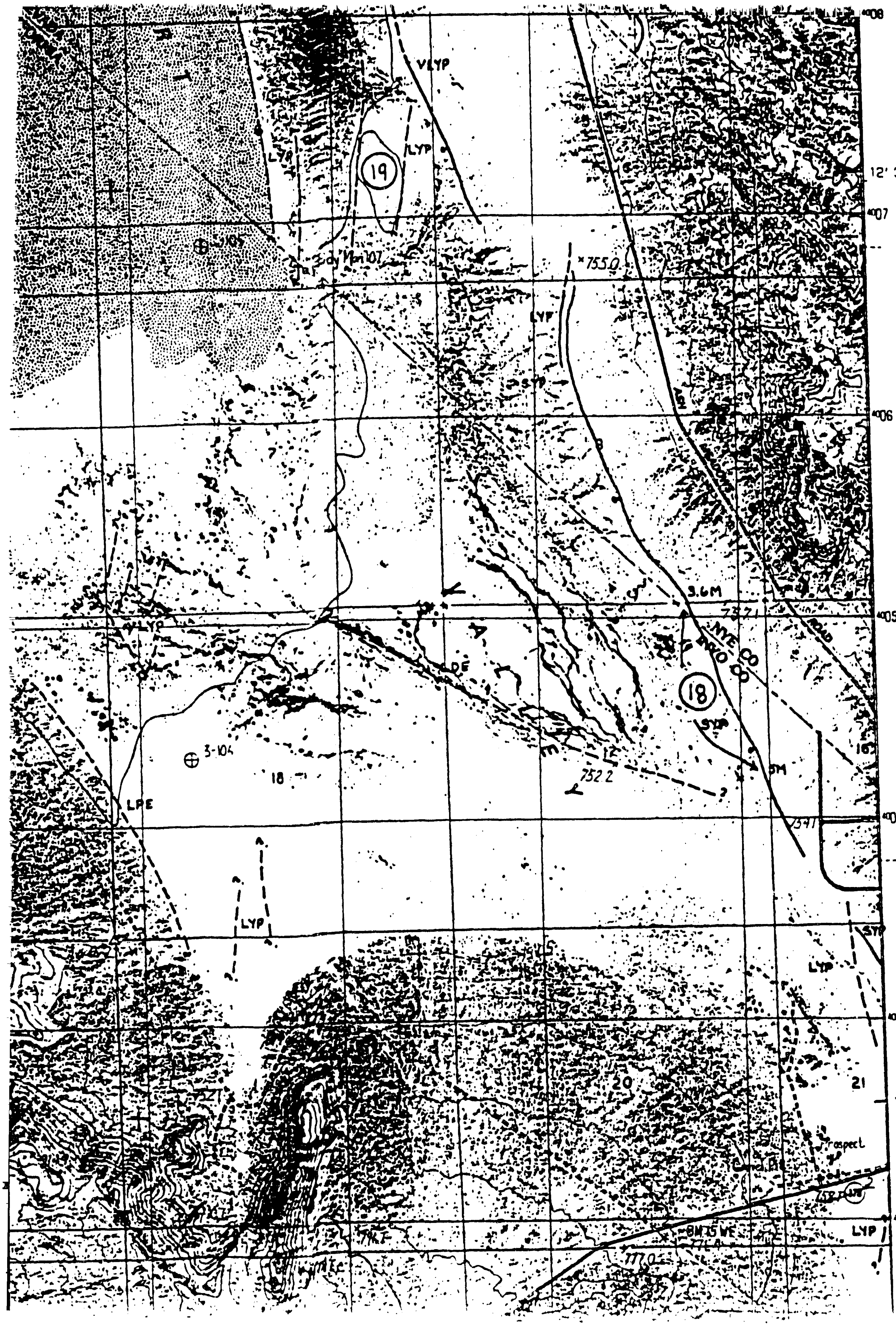
NW, 7.5' Orthophotoquad.

STEWART VALLEY NW ORTHOPHOTOQUAD
CALIFORNIA—NEVADA

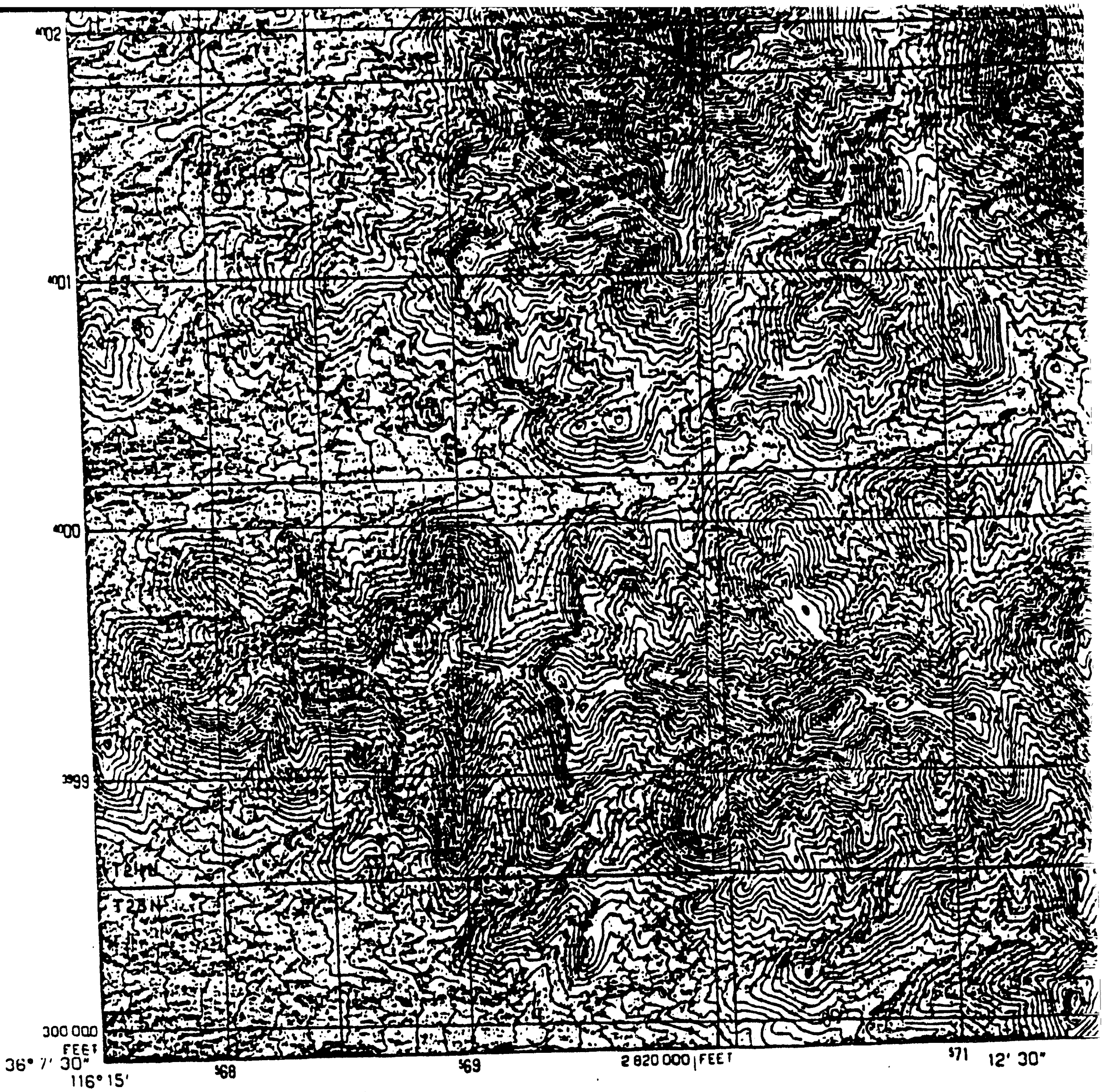



12' 30"
4007
4006
4005
4004
4003
10'
4002


LRF
LYP
VLYP 749
2
VL/LPE
VLYP
3-104
18
LPE
LYP



4008
VLYP
LYP
19
12' 30"
4007
755.0
SYP
4006
3.6M
4005
NYE CO
INYO CO
18
DE
3-104
752.2
5M
4004
LPE
4003
20
21
10'
Prospect
4002

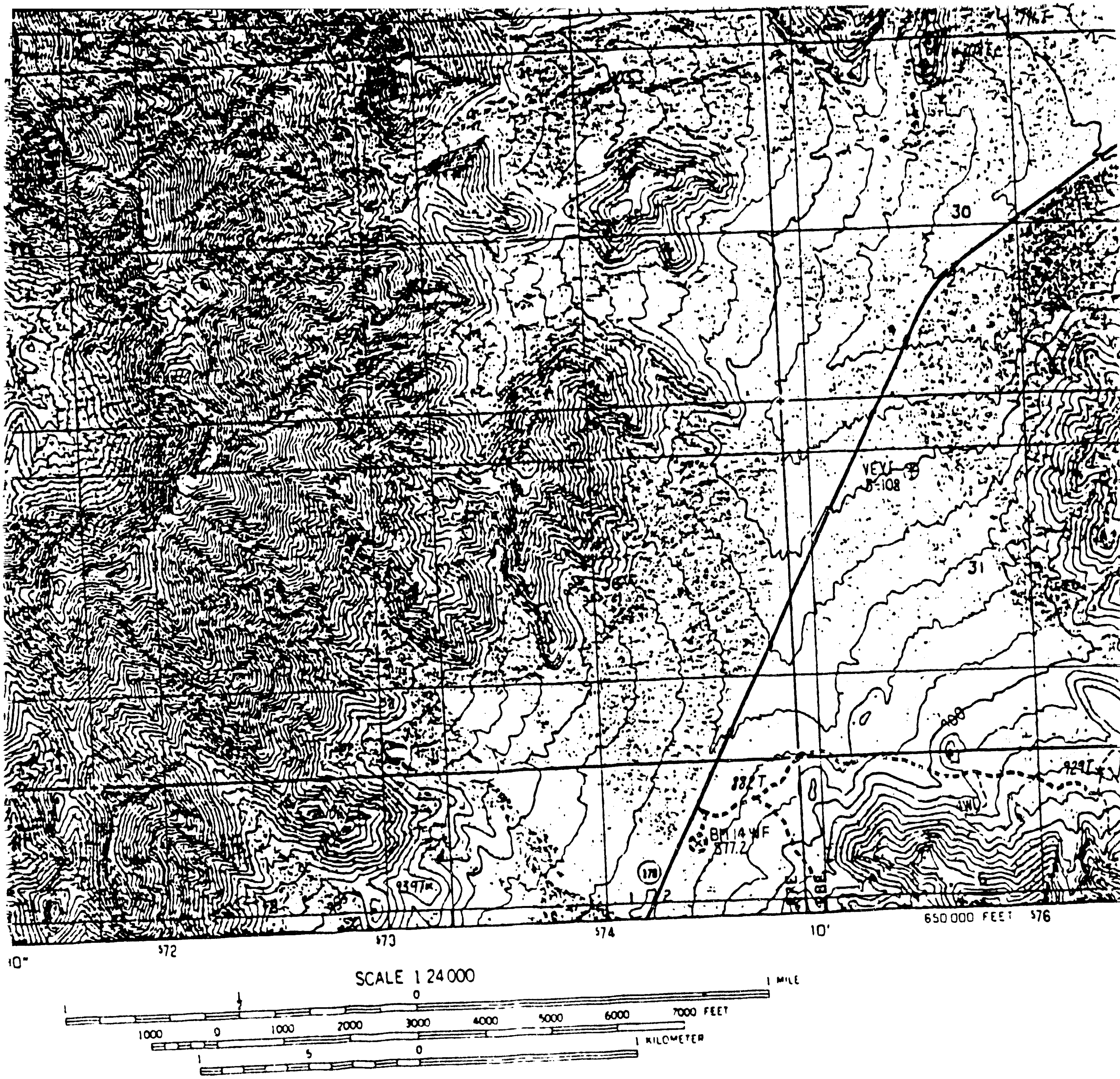


Produced by the Geological Survey
in cooperation with the Soil Conservation Service

Orthophotograph prepared from 1:80 000-scale
aerial photographs taken June 18, 1976

Projection: California coordinate system, zone 4
(Lambert conformal conic)
10,000-foot grids based on California coordinate system, zone 4
and Nevada coordinate system, central zone
1000-meter Universal Transverse Mercator grid ticks,
zone 11. 1927 North American datum

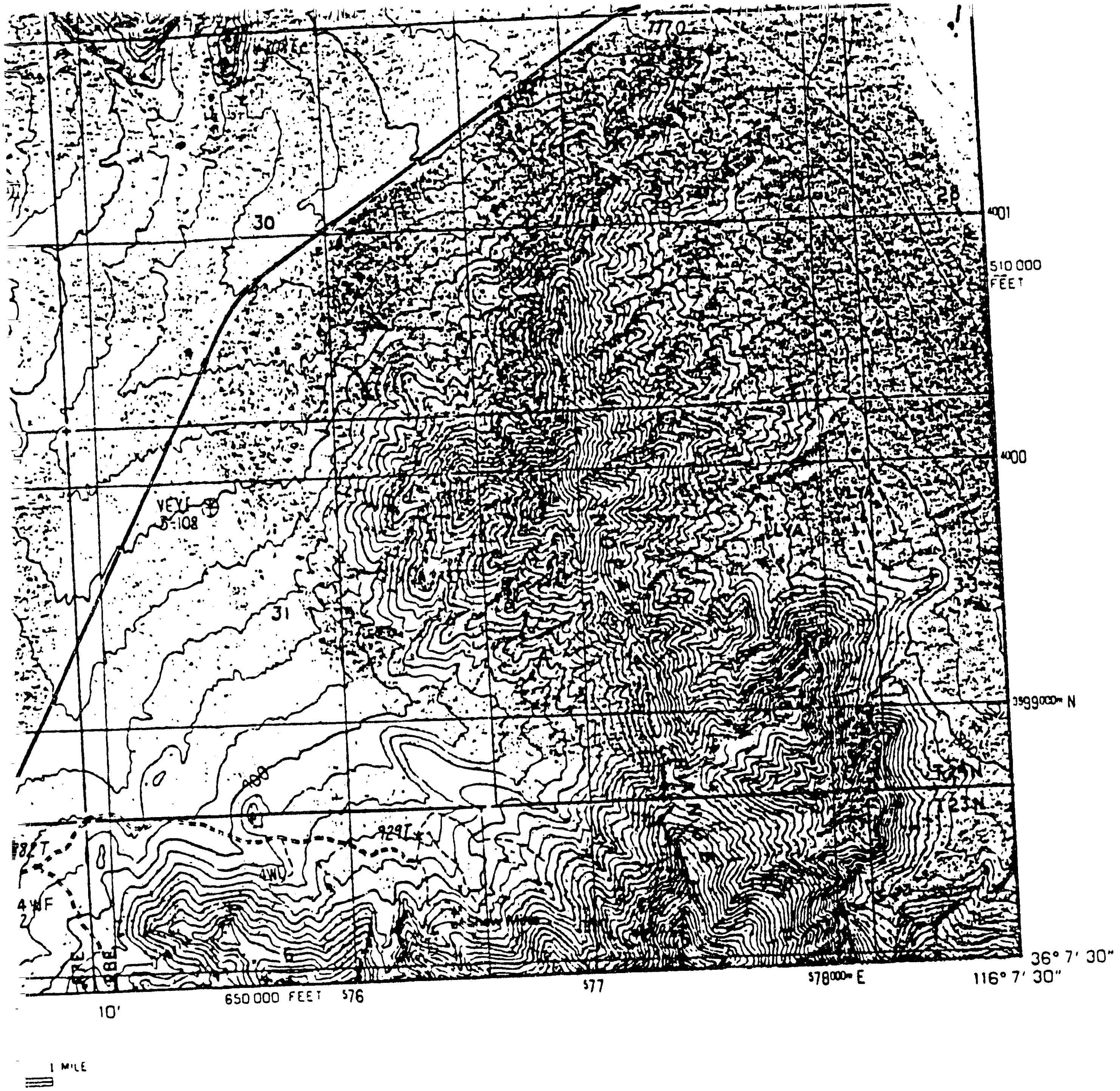
Photoimagery transformed by scanning techniques
which may produce double or mismatched images,
use the mean of image positions for map point.



by

Joanne L. Hollard

1990



STEWART VALLEY NW, CALIF.—NEV.

N3607.5—W11607.5/7.5

1976

ADVANCE PRINT

Q

OF PAH

N

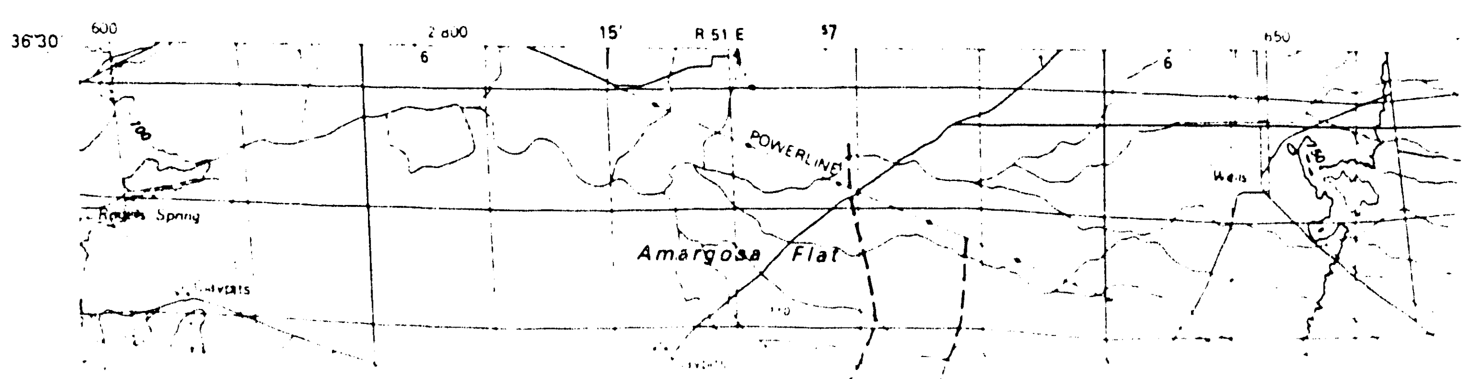


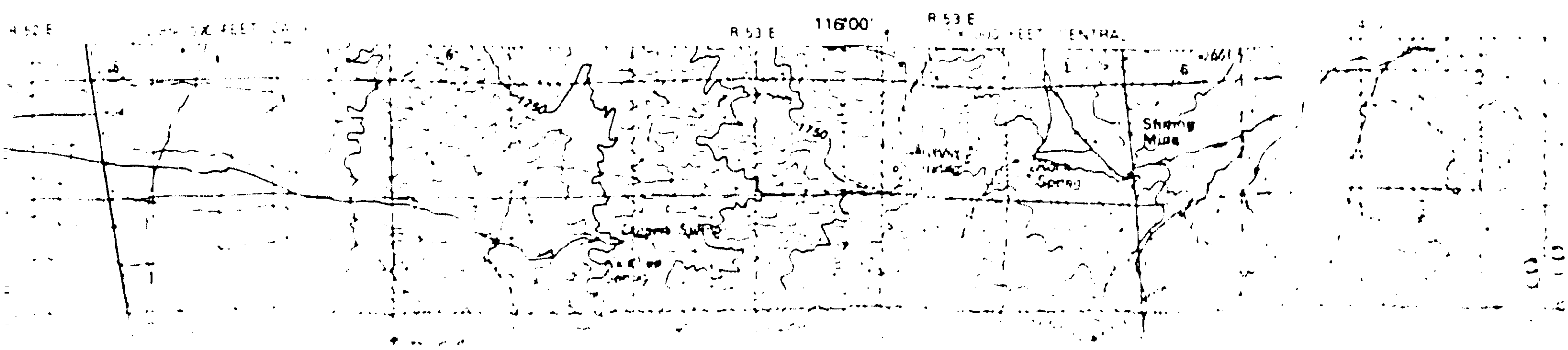
Plate 1. The Pahrump Fault Sy

UATERNARY FAUL
RUMP AND STEW
EVADA AND CALI

BY

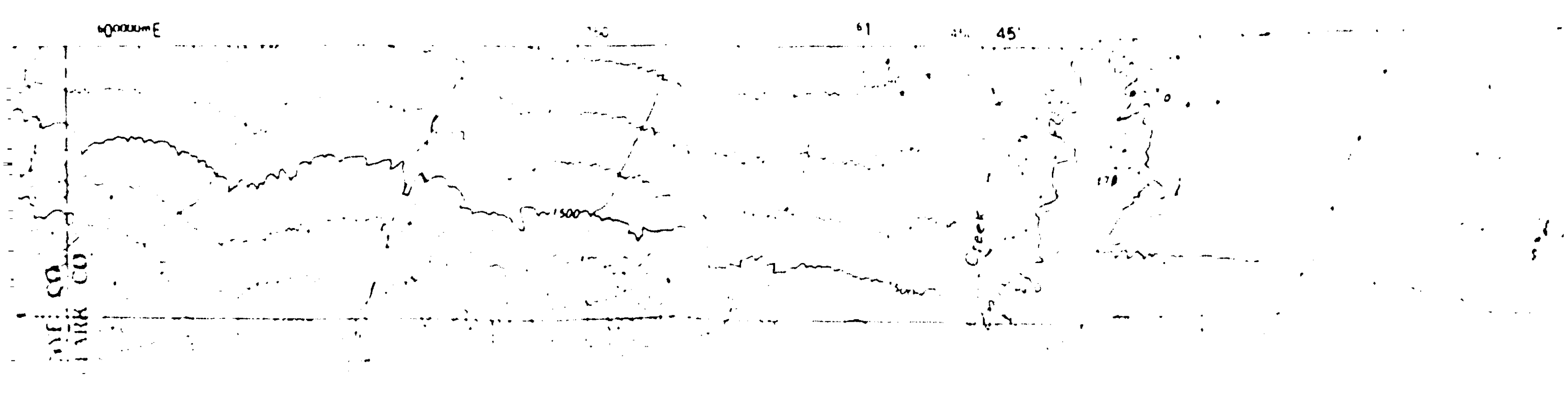
JOANNE L. HOFFAR

1990

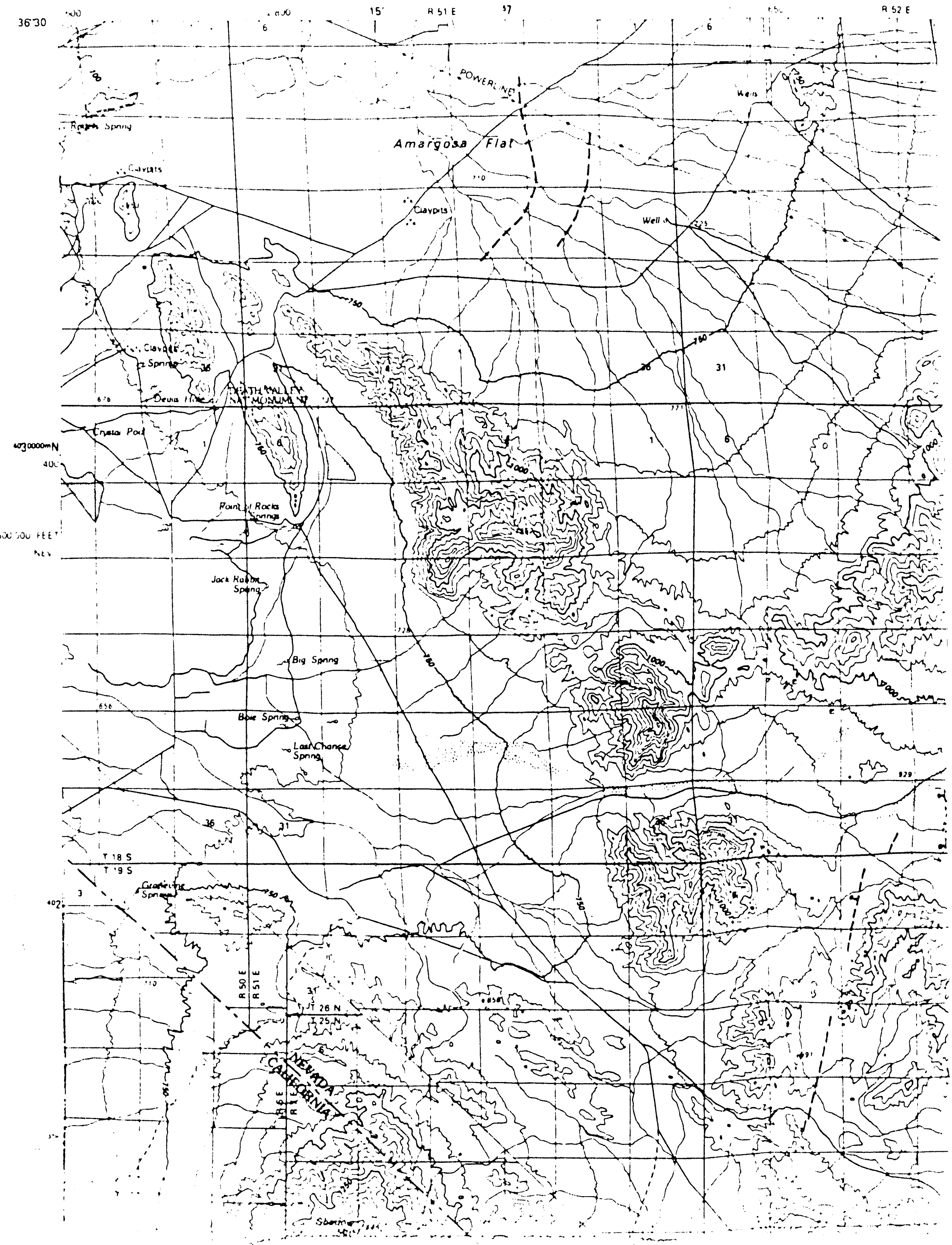


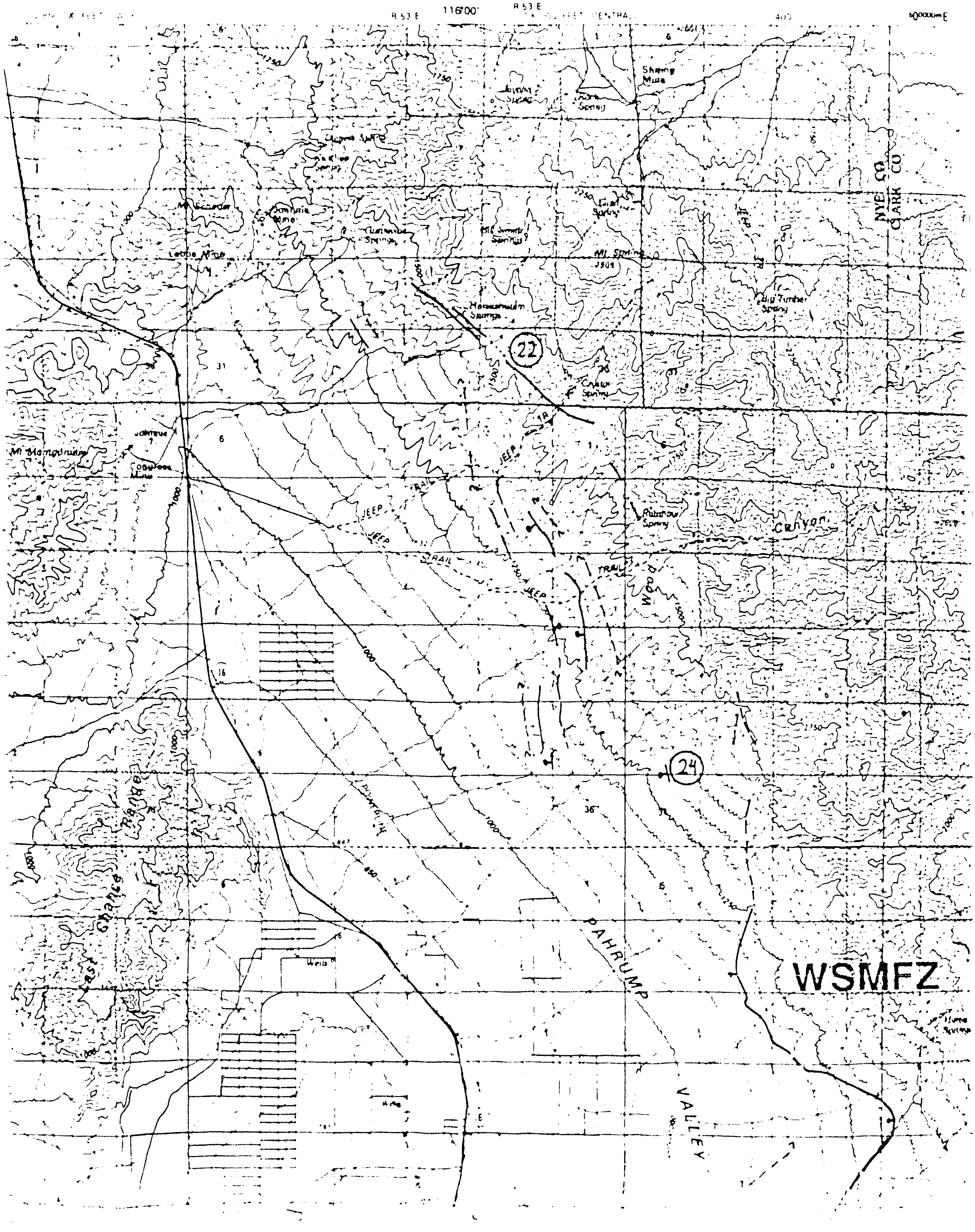
ɹLT MAP
WART VALLEYS,
.IFORNIA

ꞁRD

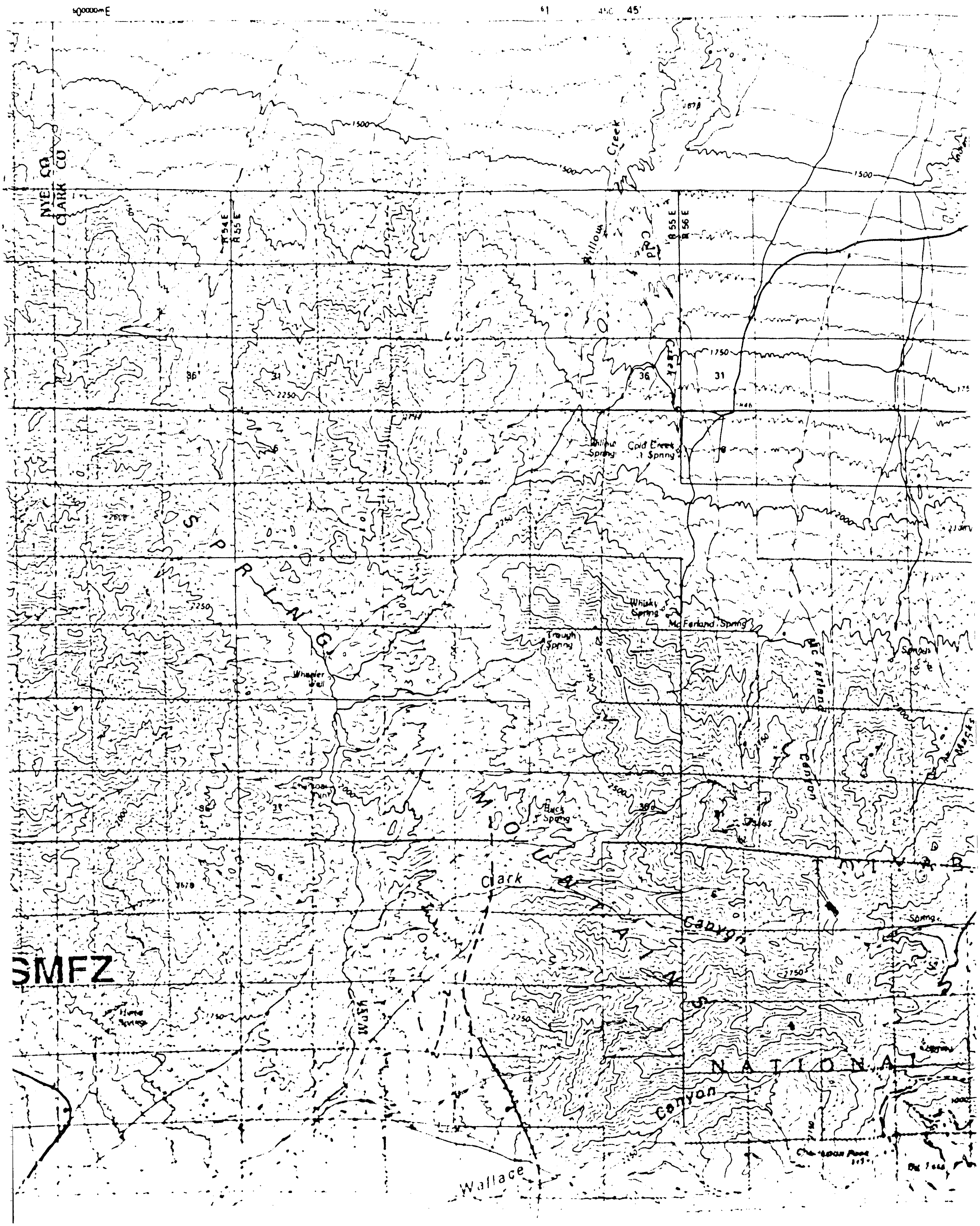


LEYS,

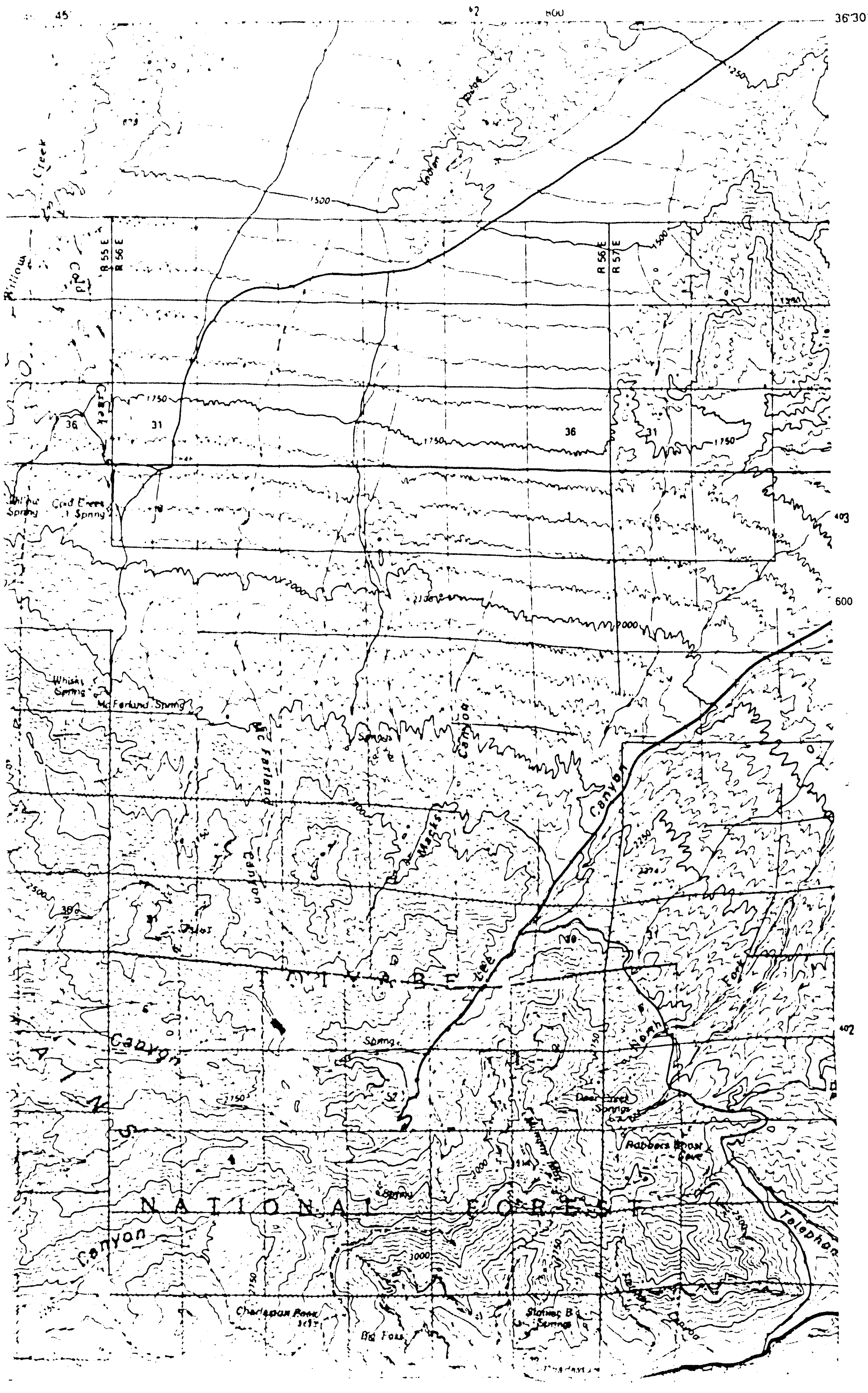

36°30
15'
R 51 E
R 52 E
POWERLINE
Amargosa Flat
Wells
Well
Claypits
Devils Hole
Crystal Pool
DEATH VALLEY NAT MONUMENT
4030000mN
600 000 FEET NEV
Point of Rocks Springs
Jack Rabbit Spring
Big Spring
Bole Spring
Last Chance Spring
T 18 S
T 19 S
Grapevine Springs
R 50 E
R 51 E
T 26 N
T 25 N
NEVADA
CALIFORNIA



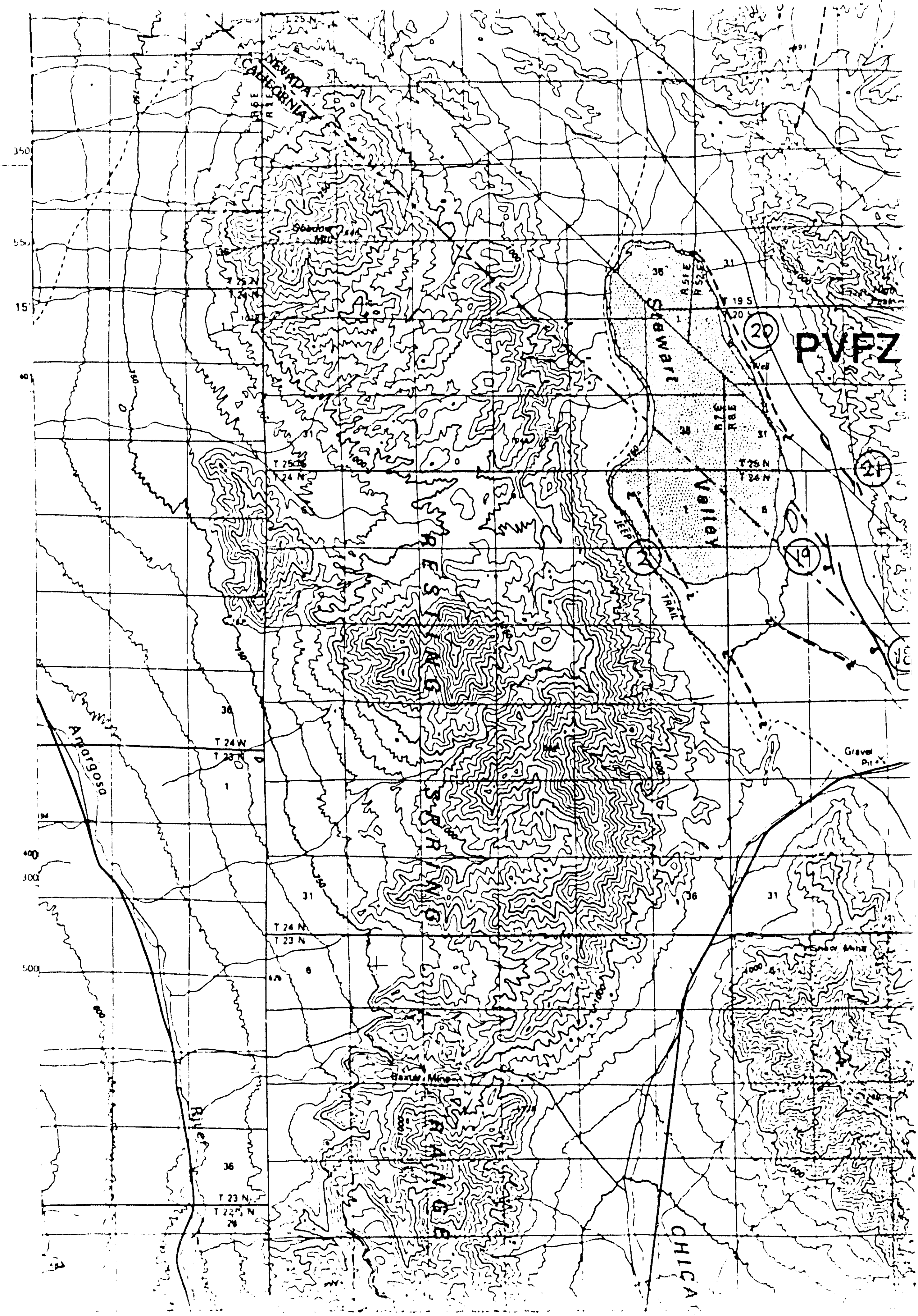
116°00'
R 53 E
NYE CO
CLARK CO
22
24
JEEP TRAIL
Wood Canyon
PAHRUMP VALLEY
WSMFZ

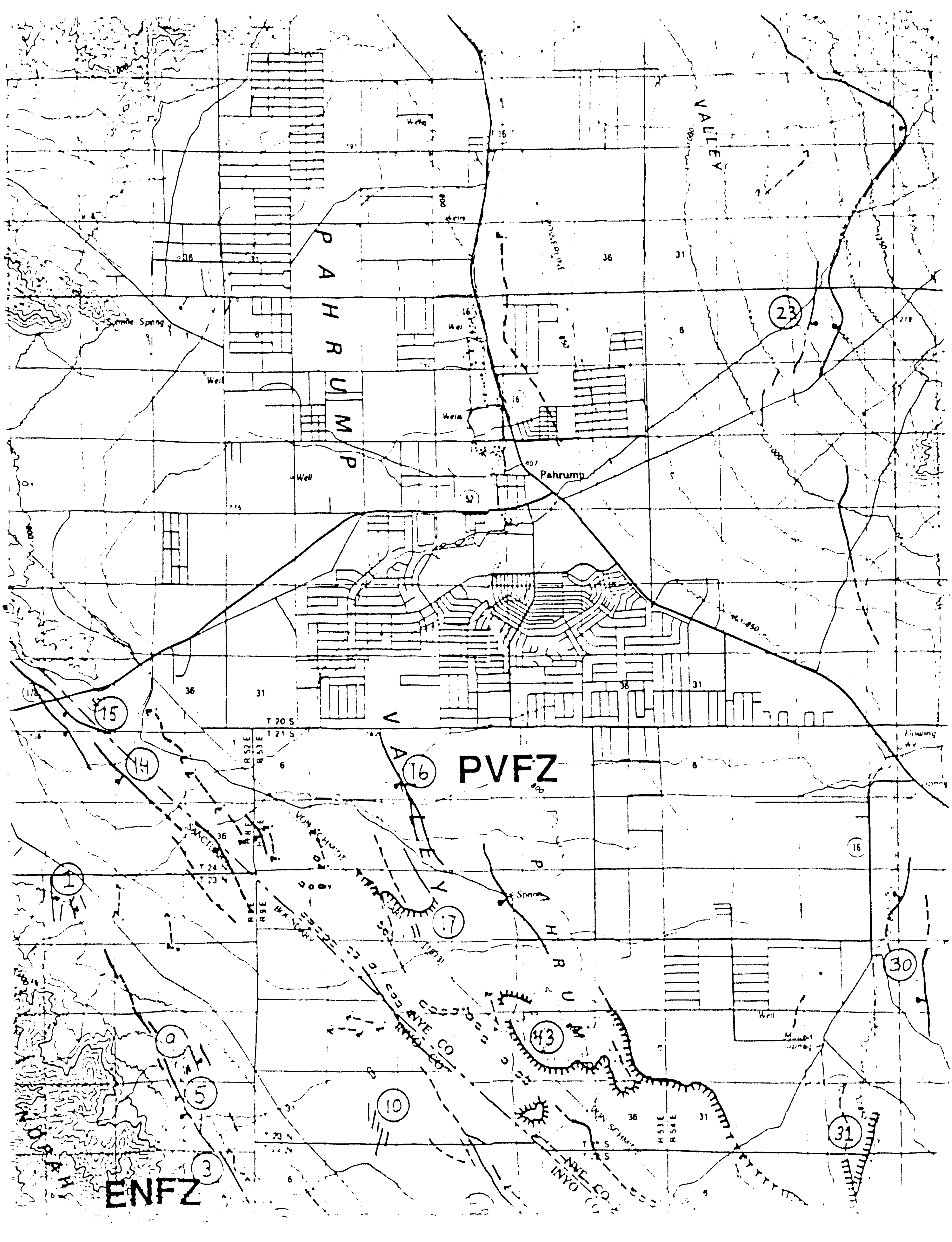


NYE CO
CLARK CO
R 54 E
R 55 E
R 56 E
Willow
Creek
Cold
Creek
Cold Creek Spring
Whisky Spring
McFarland Spring
Trough Spring
Wheeler Well
Buck Spring
SPRING
MOUNTAINS
NATIONAL
Clark
Canyon
Wallace
SMFZ
1500
1750
2000
2250
2500

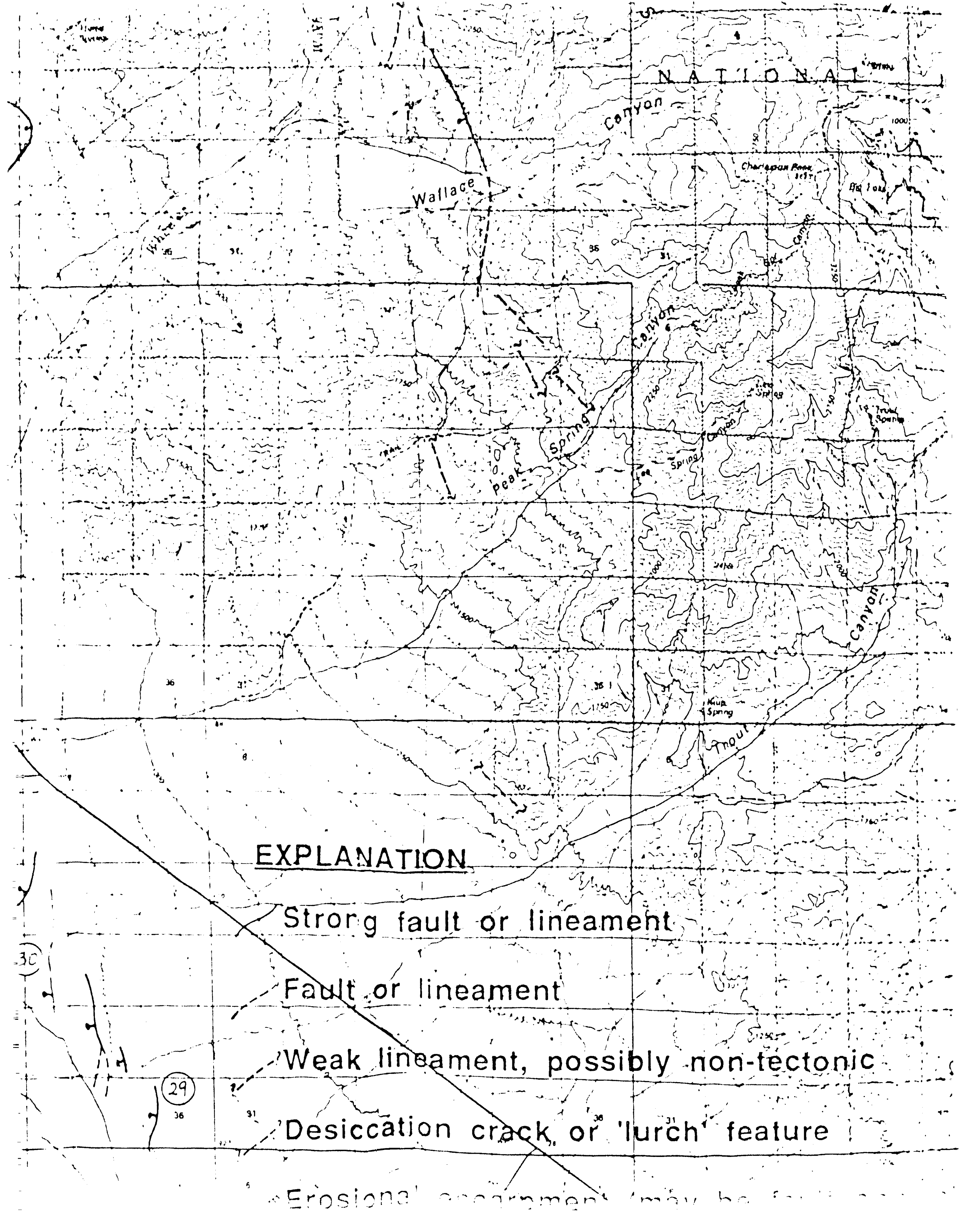


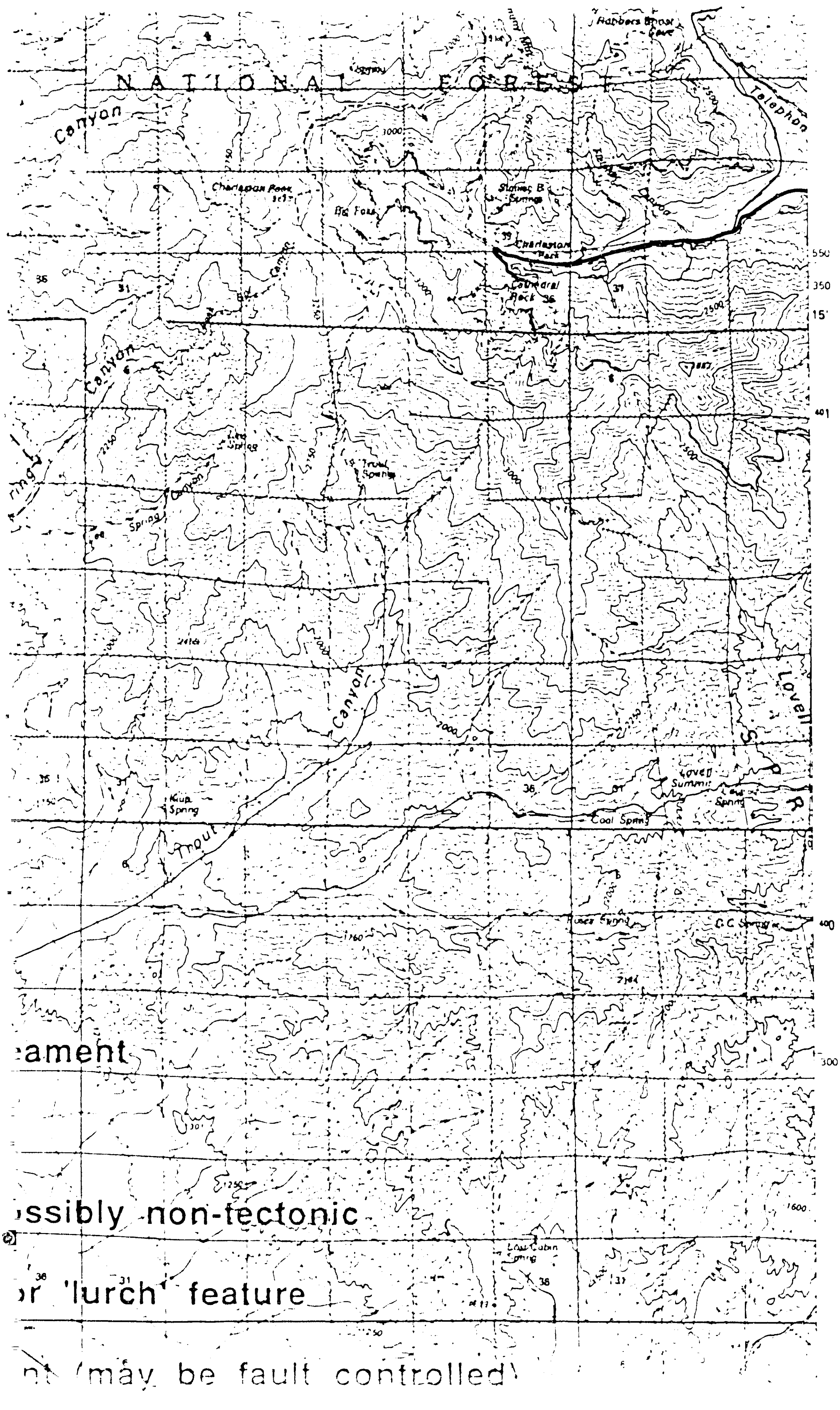
36°30'
R 55 E
R 56 E
R 56 E
R 57 E
1500
1750
2000
403
600
402
Whisky Spring
McFarland Spring
Canyon
NATIONAL FOREST
Robbers Roost Cave
Charleston Peak
Big Falls


NEVADA
CALIFORNIA
PVFZ
Stewart
Valley
JEEP TRAIL
20
21
19
RESTING
SPRING
RANGE
Amargosa
River
Gravel Pit
Baxter Mine
CHICA
T 25 N
T 24 N
T 23 N
T 19 S
T 20 S
R 8 E
36
31
1
6

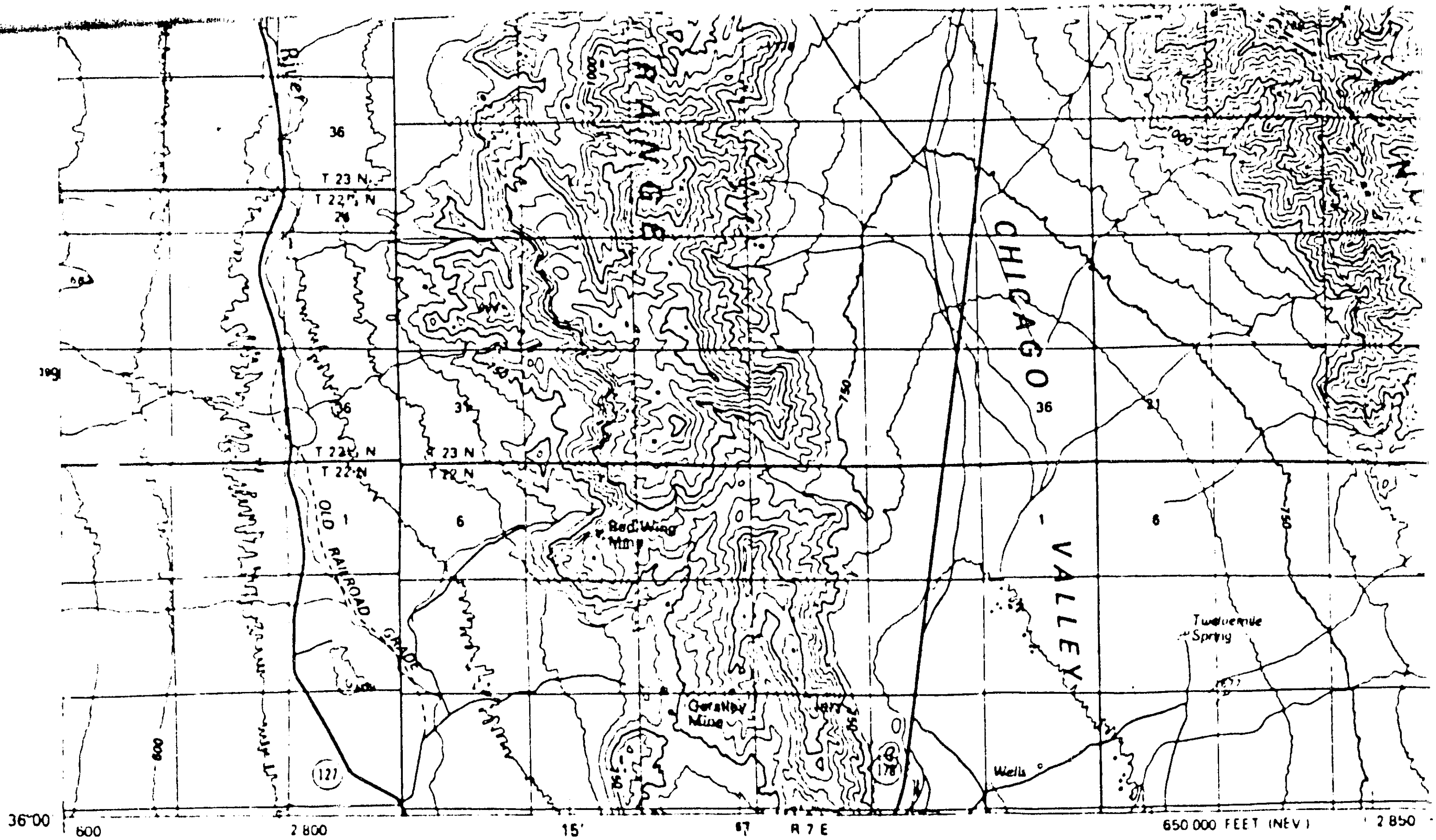


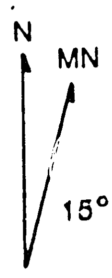
PAHRUMP
VALLEY
Pahrump
PVFZ
ENFZ
23
15
14
16
1
17
30
43
9
5
10
3
31
NYE CO
INYO CO
T 20 S
T 21 S
R 52 E
R 53 E
Well
Spring
36
31
6

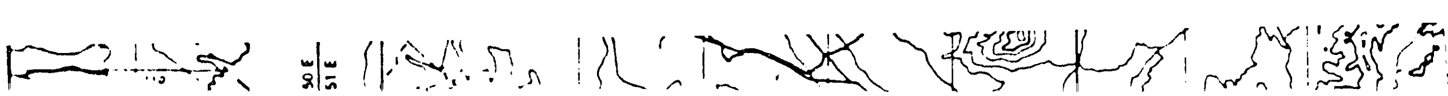

NATIONAL
Canyon
Wallace
Charleston Peak
Canyon
Spring
Canyon
Peak
Spring
Trout Spring
Canyon
Kiup Spring
Trout
EXPLANATION
Strong fault or lineament
Fault or lineament
Weak lineament, possibly non-tectonic
Desiccation crack or 'lurch' feature

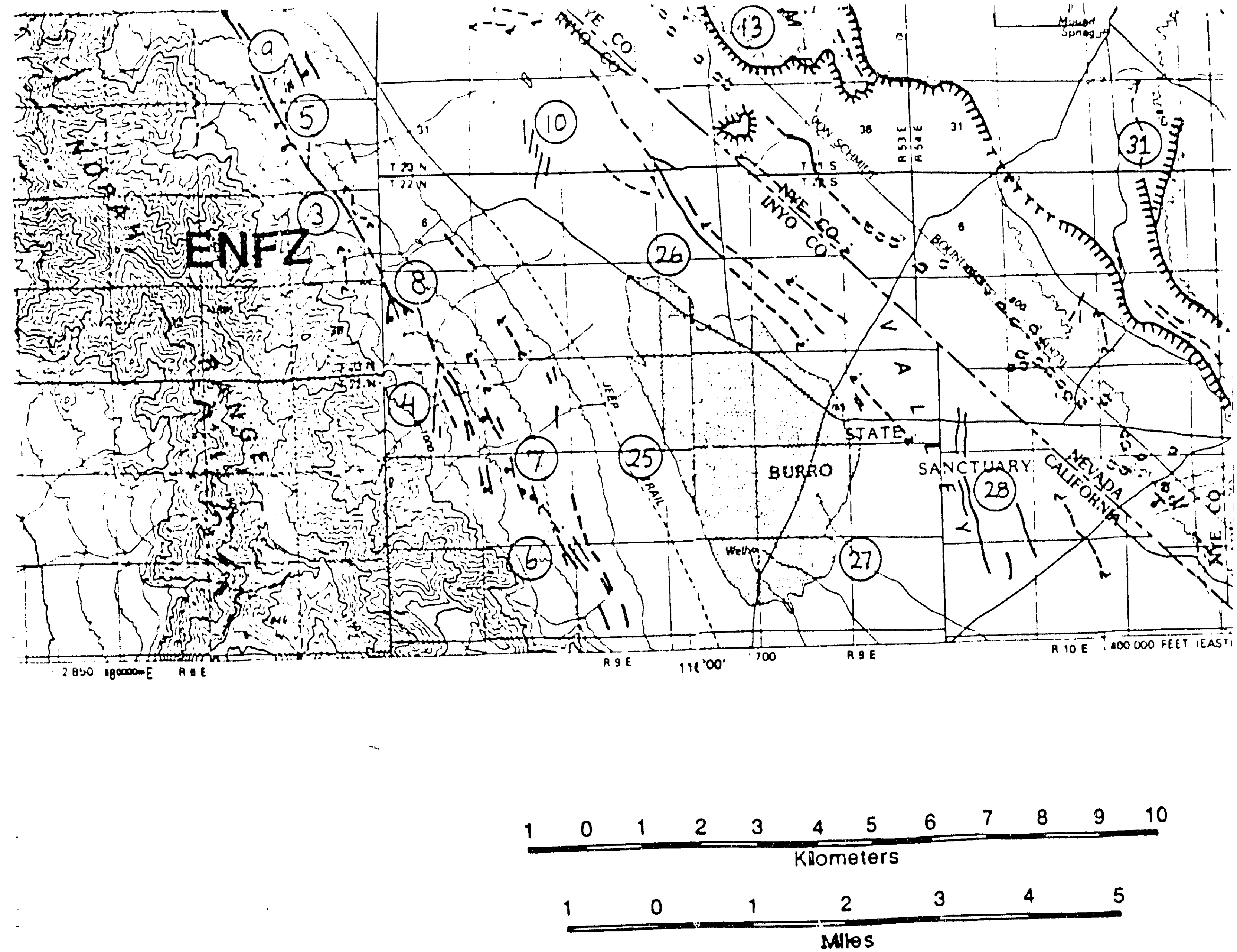


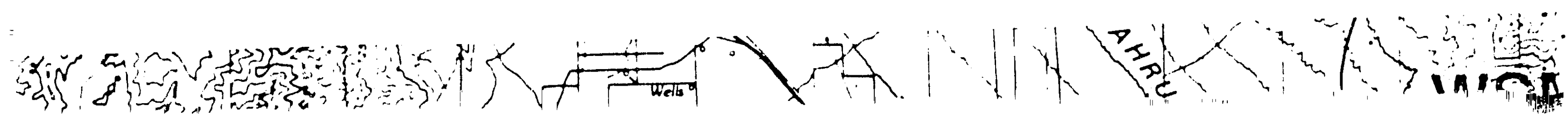
NATIONAL FOREST
Canyon
Charleston Peak
Cathedral Rock
Big Falls
Telephone
Trout Spring
Canyon
Lovell
Lovell Summit
Cool Spring
Trout
Kiup Spring
2000
2500
550
350
15'
401
400
300
1600
ament
ssibly non-tectonic
r 'lurch' feature
nt (may be fault controlled)

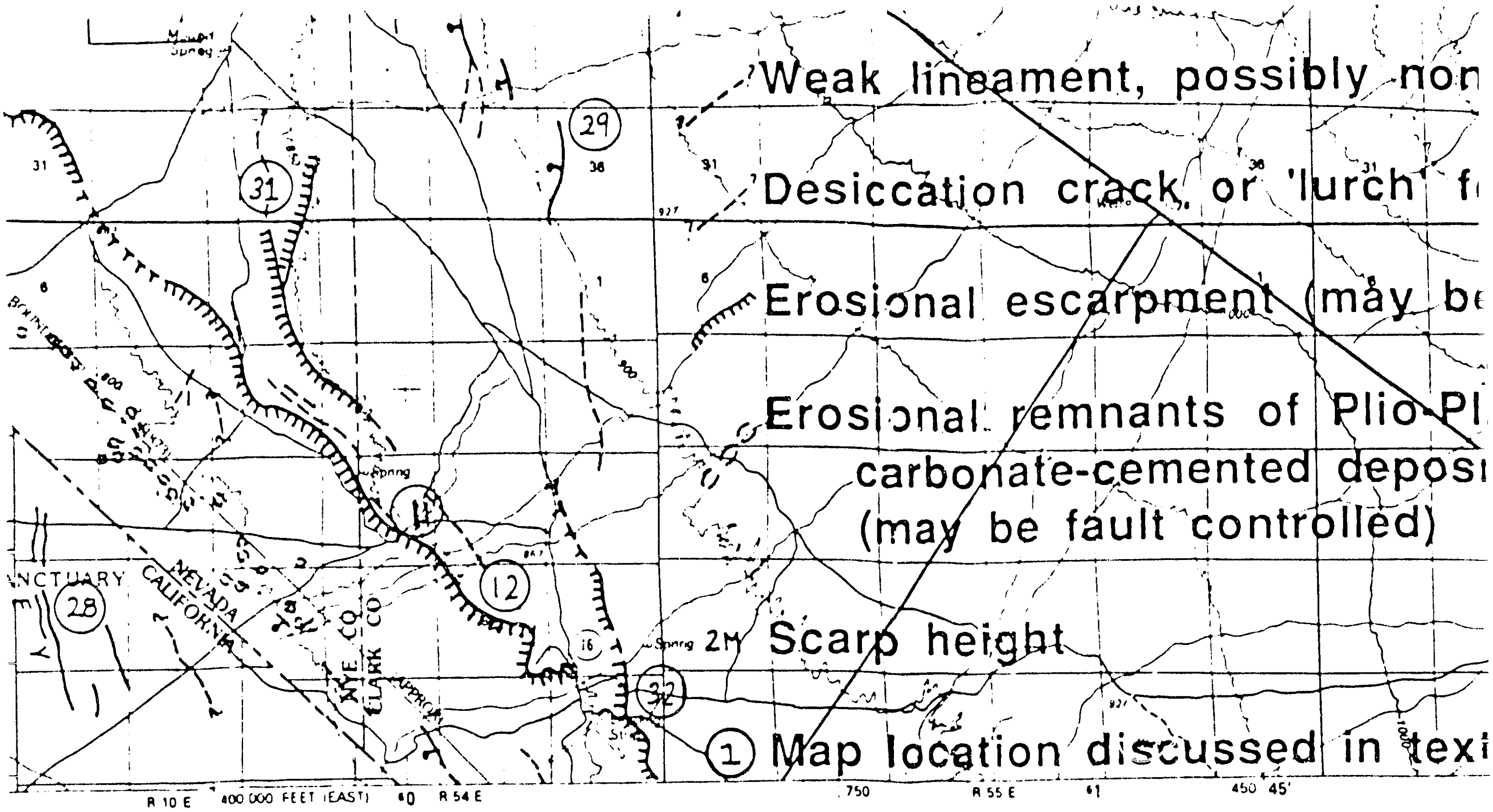

River
T 23 N
T 22 N
CHICAGO
VALLEY
OLD RAILROAD GRADE
Red Wing Mine
Gerstley Mine
Twelvemile Spring
Wells
36°00'
600
2 800
15'
R 7 E
650 000 FEET (NEV)
2 850


N
MN
15°

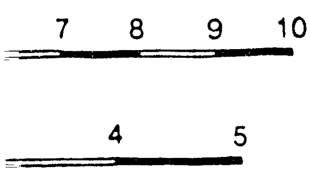



ENFZ
9
5
3
8
4
7
6
10
13
26
25
31
28
27
NYE CO
INYO CO
BURRO
STATE
SANCTUARY
NEVADA
CALIFORNIA
JEEP
TRAIL
T 23 N
T 22 N
T 1 S
T 2 S
R 53 E
R 54 E
R 8 E
R 9 E
R 10 E
400 000 FEET (EAST)
700
Wells
1 0 1 2 3 4 5 6 7 8 9 10
Kilometers
1 0 1 2 3 4 5
Miles

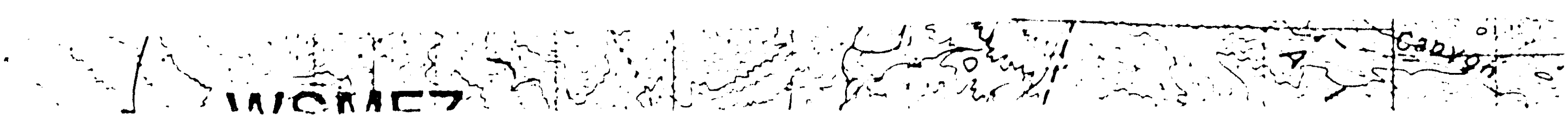

Wells



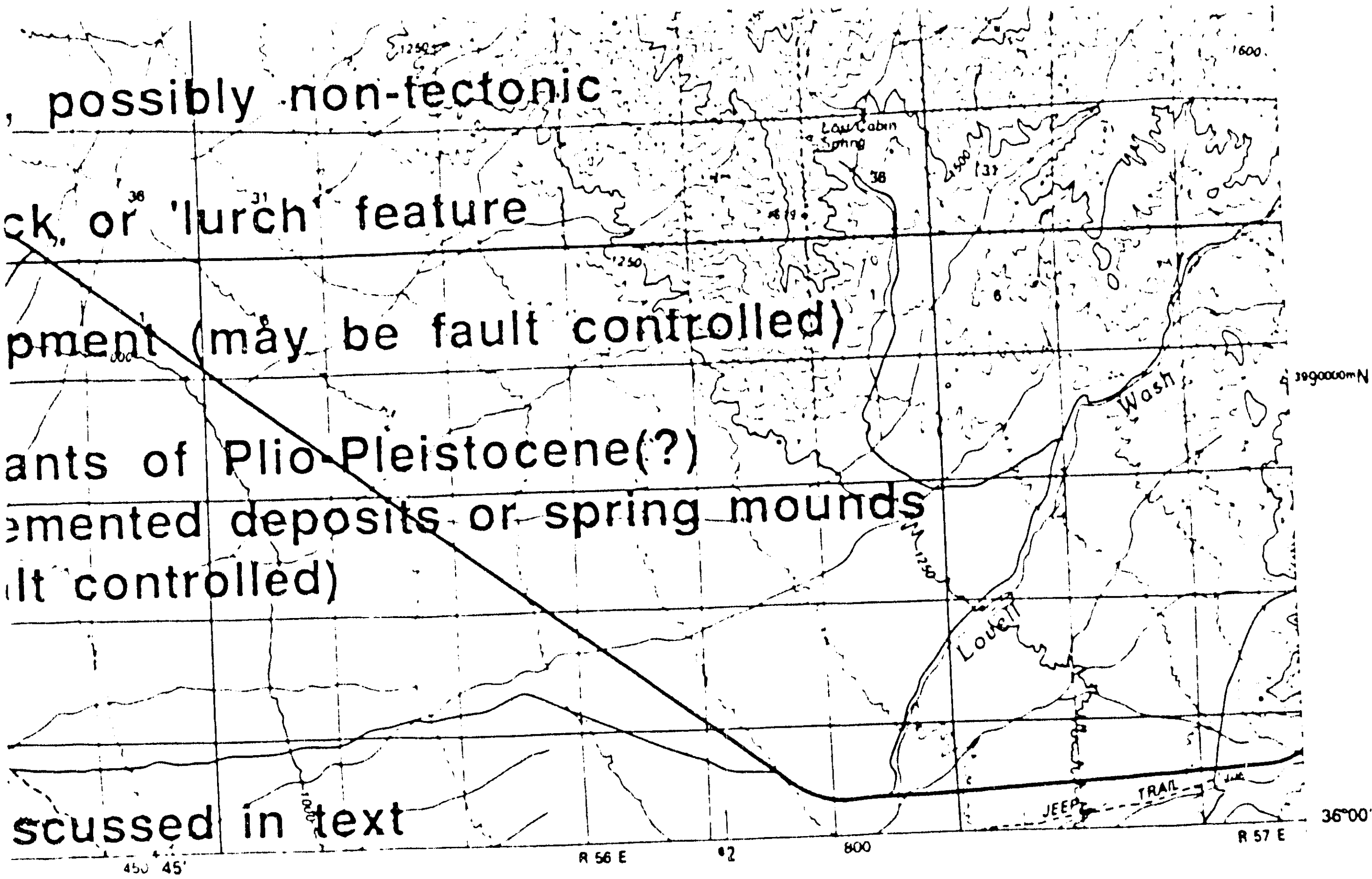
Weak lineament, possibly non
Desiccation crack, or 'lurch' f
Erosional escarpment (may be
Erosional remnants of Plio-Pl
carbonate-cemented deposi
(may be fault controlled)
2M Scarp height
1 Map location discussed in text
29
31
11
12
28
32
NEVADA
CALIFORNIA
NYE CO
CLARK CO
Spring
R 10 E
400 000 FEET (EAST)
R 54 E
750
R 55 E
450 45'

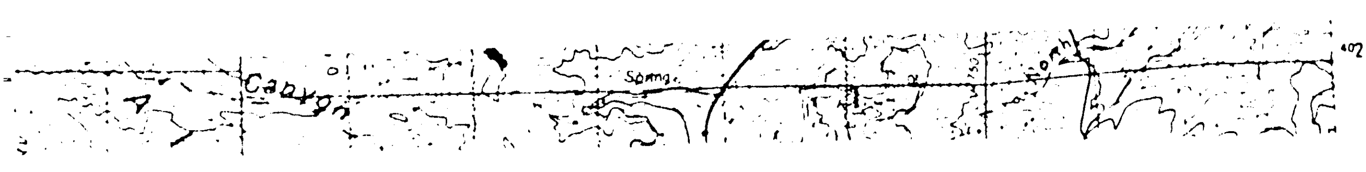


7 8 9 10
4 5



Canyon


, possibly non-tectonic
ck, or 'lurch' feature
pment (may be fault controlled)
ants of Plio-Pleistocene(?)
emented deposits or spring mounds
lt controlled)
scussed in text
Log Cabin Spring
Lovell
Wash
JEEP
TRAIL
3990000mN
36°00'
R 56 E
R 57 E
800
1250
1600
45'


Canyon
Spring
402

END

DATE FILMED

6 / 21 / 93