STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
DONALD A. HULL, STATE GEOLOGIST

OPEN FILE REPORT #0-80-2

Reconnaissance Geologic Map of the Belknap-Foley Area, Oregon

EXPLANATION

(Boundaries are approximate; statements are general; lithologies are based on hand specimen identification)

Qgf — Glaciofluvial deposits: Unconsolidated, locally stratified sand, gravel, silt, cobbles, and boulders up to 5 m in diameter, with lenses of varved silts and clays where glacial deposits predominate. Forms flat-lying to hummocky deposits on floors of stream valleys. Includes undifferentiated alluvial, terminal moraine, and glacial outwash deposits. Approximate equivalent to Qal (alluvium) of Wells and Peck (1961), Qal (alluvium) of Peck and others (1964), and Qgt (glacial till) and Qal (alluvium) of Jan (1967)

Qmt — Moraine terrace deposits: Unconsolidated, unstratified sand, gravel, silt, cobbles, and boulders, with lenses of varved silts and clays. Forms blanket on lower portions of slopes of McKenzie River and Horse Creek valleys upstream from Rainbow. Composed of undifferentiated lateral moraine, glacial outwash, and talus deposits

Qls — Landslide deposits: Unconsolidated blocks of bed rock and debris moved downslope via debris flows and slumping from undercutting by stream action. Material size ranges from silt- and clay-size particles to blocks 1/4 km in longest dimension. Prominent scarps are normally present at heads of slides. Partially equivalent to Qls (landslide) of Swanson and James (1975a)

Qbh — Pleistocene to Holocene basalts of the High Cascades: Holocene, black, glassy, olivine-bearing, vesicular, basaltic flow tongues; flow structures common and pronounced; overlies recent glacial and fluvial deposits in stream valleys. Found on north fork of McKenzie River, Anderson Creek, and Lost Creek White Branch. Approximately equivalent to "Anderson Creek flows" and "Sims Butte flows" of Taylor (1968); partially equivalent to Qv (volcanic rocks of the High Cascades) of Callaghan and Buddington (1938), Qb (basalt) and QTba (basalts and andesites) of Wells and Peck (1961), QTv (volcanic rocks of the High Cascades . . . undivided) of Peck and others (1964), and T/Qgb (glomeroporphyritic basalt) of Jan (1967)

QTv — Pliocene to Pleistocene basalts of the High Cascades: Upper Pliocene to Pleistocene light- to medium-gray, diktytaxitic, glomeroporphyritic to aphyric, olivine-bearing basaltic flows, with euhedral to subhedral plagioclase phenocrysts. Occurs as major rock type east of Horse Creek and north fork of McKenzie River, as an intracanyon multiple-flow unit at Foley Ridge, and as erosional remnants on the north side of the McKenzie River valley near Rainbow and McKenzie Bridge. Major source is thought to be large shield and composite volcanoes of the High Cascade platform east of the study area. Mapped separately from unit *Tpv* on basis of stratigraphic position and K/Ar age dates. Flat areas tend to be blanketed by glacial moraine and outwash deposits. Partially equivalent to Qv (volcanic rocks of the High Cascades) of Callaghan and Buddington (1938), QTba basalts and andesites) of Wells and Peck (1961), and QTv (volcanic rocks of the High Cascades . . . undivided) of Peck and others (1964)

Tpv — Pliocene volcanic rocks: Lower to middle Pliocene, medium- to light-gray, diktytaxitic, glomeroporphyritic to aphyric, olivine-bearing basaltic andesite flows, with euhedral to subhedral plagioclase phenocrysts. Includes interflow pyroclastic and epiclastic rocks and small incised phreatic cinder cone on east flank of Frissell Point. Caps ridges east of Blue River and Cougar Reservoir and west of Horse Creek and north fork of McKenzie River. Major source is thought to be large shield and composite volcanoes east of study area. Unit is defined on basis of lithology, stratigraphic position, and K/Ar dates and includes all similar rocks of Pliocene age (unit *QTv* excluded). Partially equivalent to Qv (volcanic rocks of the High Cascades) of Callaghan and Buddington (1938), QTba (basalts and andesites) of Wells and Peck (1961), QTv (volcanic rocks of the High Cascades . . . undivided) of Peck and others (1964), T/Qgb (glomeroporphyritic basalt) of Jan (1967), and "Pliocascade volcanics" of Swanson and James (1975a)

Tmdc — Dacite of Castle Rock: Upper Miocene, medium- to light-gray, dense, quartz-bearing dacitic rocks. Occurs at Castle Rock intruding flows of unit *Tmv*; includes related plug, flow rock, and sparse interflow pyroclastic rocks. Partially equivalent to Ta (volcanic rocks of the Western Cascades) of Callaghan and Buddington (1938), Tmua (andesite and basalt) of Wells and Peck (1961), and Tsa (Sardine Formation andesite) of Peck and others (1964)

Tmvd / Tmv / Tmvi — Miocene volcanic rocks: Miocene basaltic, andesitic, and dacitic lava flows and autobreccias and, to a lesser extent, tuffs, lapilli tuffs, ash flows, mudflows, debris flows, and minor epiclastic rocks. Dark-gray to black, dense, porphyritic, two-pyroxene andesites with large plagioclase phenocrysts predominate, but aphyric basaltic rocks are also common. Mafic minerals are generally altered to green clay minerals, with degree of alteration increasing toward base of unit. Flow contacts are readily identifiable in outcrop, and several unconformities are present within unit. Caps ridges west of Lookout Mountain and Cougar Reservoir and is dominant rock type east of Lookout Mountain and Cougar Reservoir and west of Horse Creek and north fork of McKenzie River. Limited outcrops underlie unit *Tpv* near Scott Creek and eastern edge of Foley Ridge. Unit is defined on basis of lithology, stratigraphic position, and K/Ar dates and includes all similar rocks of Miocene age (unit *Tmdc* excluded). Several large intrusive and remnant volcanic plugs are mapped separately as unit *Tmvi*, and basaltic and andesitic dikes in Blue River valley are mapped separately as unit *Tmvd*. Partially equivalent to Ta (volcanic rocks of the Western Cascades) of Callaghan and Buddington (1938) and "basalt" of Tuck (1927). Approximate time-stratigraphic equivalents of Tmua (andesite and basalt) of Wells and Peck (1961), Tsa (Sardine Formation andesite) of Peck and others (1964), Tsf (basaltic and basaltic andesite flows and breccias) of Jan (1967), "Sardine Formation" of Swanson and James (1975a), and "Sardine Formation" of Storch (1978)

Tmd — Miocene dioritic rocks: Middle (?) Miocene, light-gray, aphanitic, equigranular, quartz-bearing diorite; crops out locally in Tidbits Creek drainage in Blue River mining district, intruding flows of lower *Tmv* unit. Approximately equivalent to Ti (intrusive igneous rocks) of Callaghan and Buddington (1938) and Tg (granodiorite) of Peck and others (1964)

Tov — Oligocene (?) volcanic rocks: Oligocene (?) lithic tuffs, lapilli tuffs, rock-fragment-rich laharic tuffs, volcanic breccias, and epiclastic rocks, and, to a lesser extent, black, dense, basaltic and andesitic autobreccias and flows. Pyroclastic rocks are generally highly sheared and massive in outcrop and altered to contain green, greenish-brown, and light-brown, low-grade metamorphic minerals. Lava flows are generally highly altered, with mafic minerals wholly altered to green and white clay minerals. Margins of flows are obscured in outcrop by numerous shear zones filled with clay, calcite, and green to white quartz and chalcedony. Unit is easily discernible from unit *Tmv* in outcrop on basis of lithology, relative degree of alteration, and shearing. Unit is dominant rock type west of Lookout Mountain and Cougar Reservoir. Unit is defined on basis of lithology and stratigraphic position and includes all similar rocks lying below unit *Tmv*. Partially equivalent to "andesite-agglomerate" of Tuck (1927) and Ta (volcanic rocks of the Western Cascades) of Callaghan and Buddington (1938). Approximate time-stratigraphic equivalent of Tmop (pyroclastic rocks) of Wells and Peck (1961), Tlt (Little Butte Volcanic Series tuffs) of Peck and others (1964), and "Little Butte Formation" of Swanson and James (1975a)

22.1 ⊕ 150 / 80 / 83:
- GRADIENT (°C Km⁻¹)
- DEPTH PROBED
- HOLE LOCATION
- HEAT FLOW (mWm⁻²)
- BOTTOM HOLE TEMP. (°C)

86 — THERMAL SPRING; WATER TEMP. (°C)

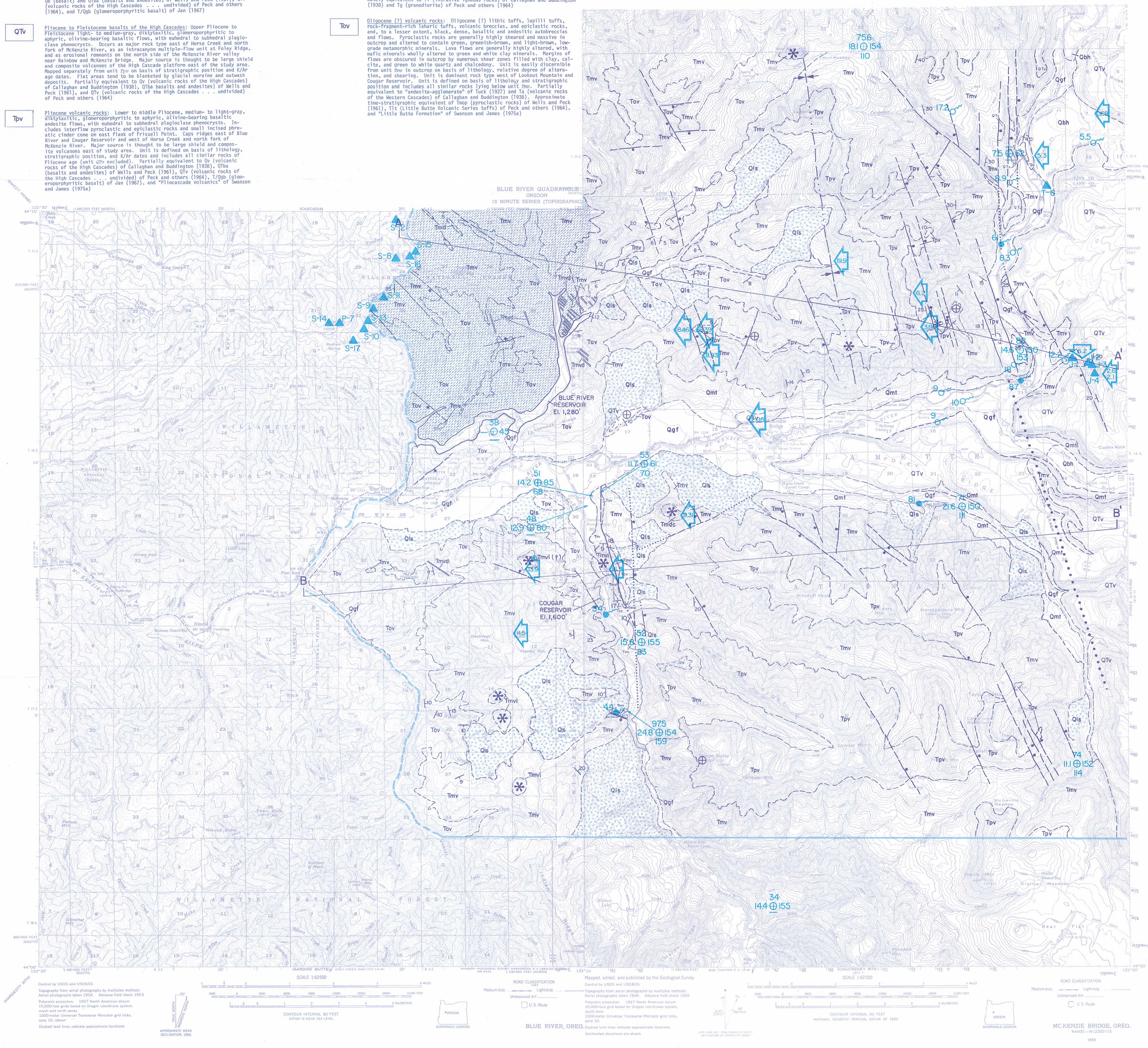
12 — COLD SPRING; WATER TEMP. (°C)

79 — K/Ar AGE—DATE LOCATION

P-29 — ROCK CHEMISTRY LOCATION WITH TEXT REFERENCE

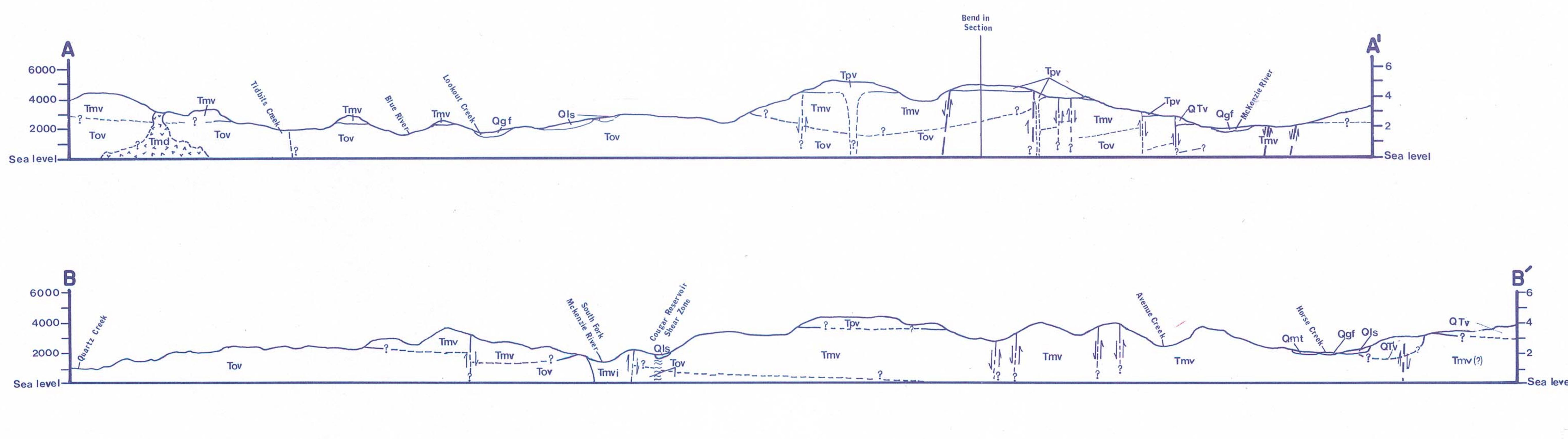
GEOLOGIC SYMBOLS

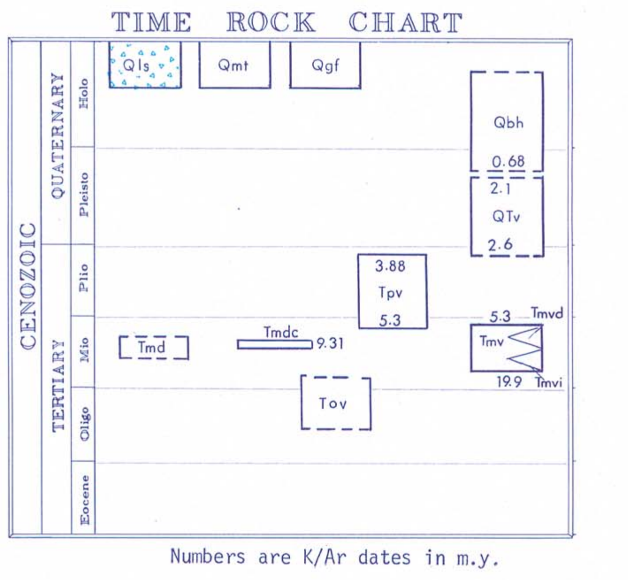
- Contacts - All contacts for this study are approximately located and based on reconnaissance mapping only
- Normal fault - Solid where exposed, dashed where inferred, dotted where concealed, ball and bar on downdropped side
- Syncline - Dashed where inferred
- Strike and dip of beds
- Flat-lying beds
- Volcanic center - Includes volcanic pipes, necks, plugs, and shield volcanoes
- Areas of general rock alteration - Areas of propylitic to argillic alteration. Alteration suite includes deposits of one or more of the following: quartz, chalcedony, limonite, pyrite, barite, hematite, specularite, pyrrhotite, and clay minerals



Geology by David E. Brown, Gary D. McLean, George Priest, Neil M. Woller, and Gerald L. Black. Adapted from Callaghan and Buddington, 1938; Wells and Peck, 1961; Peck and others, 1964; Jan, 1967; Taylor, 1968; and Swanson and James, 1975a

Geologic Cross Sections





Numbers are K/Ar dates in m.y.

BrowDE1980c

STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
1005 State Office Building
Portland, Oregon 97201

OPEN-FILE REPORT O-80-2

PRELIMINARY GEOLOGY AND GEOTHERMAL RESOURCE POTENTIAL OF THE BELKNAP-FOLEY AREA, OREGON

by

D. E. Brown,

G. D. McLean,

G. R. Priest,

N. M. Woller, and

G. L. Black

Under the direction of J. F. Riccio

Study completed under U. S. Department of Energy
Cooperative Agreement No. DE-FC07-79ET27220

1980

DISCLAIMER

This report has not been edited for complete conformity with Oregon Department of Geology and Mineral Industries standards. Data in this document are preliminary and are subject to change upon further verification.

CONTENTS

ILLUSTRATIONS

FIGURES

TABLES

MAPS (folded, in envelope)

INTRODUCTION

The Belknap-Foley area is located in the central Western Cascade Range of Oregon, approximately 80 km (50 mi) east of Eugene (Figure 1). Limits of the study area were arbitrarily assigned by U.S. Geological Survey (USGS) topographic map limits and natural breaks in the geology and topography (Plate I). This study, performed under U.S. Department of Energy (USDOE) Contract No. DE FC07-79ET27220, was undertaken to estimate the geothermal potential of the area by using various methods including compilation of existing data, reconnaissance geologic mapping, lineament analysis, well and spring geochemistry, and accrual of geothermal-gradient data.

Geographically, the study area is located in the rugged mountains surrounding the valley of the McKenzie River, which bisects the area in an east-west direction. Total relief is approximately 1,000 m (3,300 ft) in the mountainous areas and approximately 30 m (100 ft) in the river valley.

GEOLOGY

Introduction

The Belknap-Foley area is located at the eastern boundary of the Western Cascades geologic province in the Western Cascades-High Cascades transition zone. Quaternary and late Tertiary lavas and minor tuffs of the High Cascades province are in steep depositional contact with older Western Cascades rocks along this boundary, which appears to be the western margin of a major north-south-trending High Cascades graben (Allen, 1966; Taylor, 1978, 1980). Because a number of thermal springs and preexisting gradient holes with high values are located along the margin of this graben, much of the mapping effort of this study was directed at carefully defining the nature of the High Cascades-Western Cascades geologic boundary.

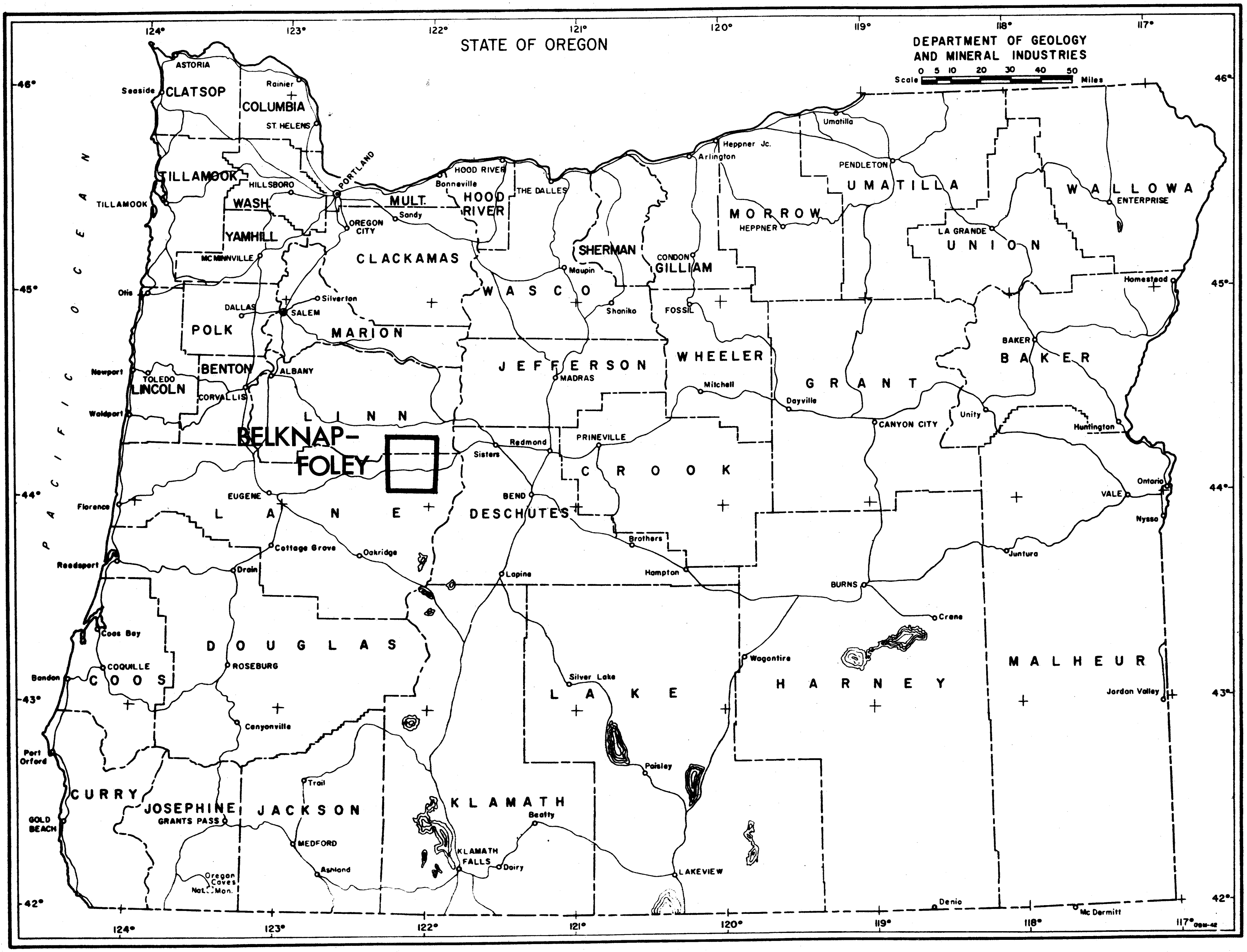


Figure 1: Map showing location of study area.

The geology and all K/Ar radiometric ages (Table 1) are presented on the accompanying reconnaissance geologic map (Plate I), which was produced during the summer and fall of 1979 and 1980. Areal extent of geologic units was based on mapping and hand-specimen identification of rocks. Data were plotted on USGS topographic maps without the aid of aerial photographs.

Volcanic stratigraphy

From middle Tertiary to Quaternary time, volcanism in the area changed from silicic pyroclastic activity to eruption of increasingly mafic magmas (Table 2). This change in composition was reflected in higher percentages of lavas relative to tuffs. The oldest mappable unit (unit *Tov* on the geologic map) is composed of epiclastic volcanic sedimentary rocks, lithic-fragment-rich laharic dacite tuffs, and minor mafic lava flows. These rocks are probably Oligocene to early Miocene in age (Peck and others, 1964). In the Blue River mining district, the Oligocene rocks are locally intruded by Miocene quartz-bearing dioritic stocks (unit *Tmd*). The Miocene sequence (unit *Tmv*) is dominated by highly phyric lavas, autobreccias, and mudflows with two-pyroxene andesite clasts, although lesser volumes of ash-flow, air-fall, and epiclastic tuffs as well as some basaltic flows occur locally. Several Miocene volcanic plugs and plug domes (unit *Tmvi*) occur in the western part of the area, and basaltic to andesitic feeder dikes (unit *Tmvd*) occur in the Blue River valley. The oldest dated rock assigned to the Miocene volcanic sequence in the map area is 19.91±1.94 m.y. old (McBirney and others, 1974). The youngest dated *Tmv* sample is 6.2±0.2 m.y. old (Laursen and Hammond, 1978). The Miocene rocks are overlain by diktytaxitic to compact basaltic to basaltic-andesitic lavas and one small ash flow which cap most of the high ridges in the western part of the area. These Pliocene volcanic rocks (unit *Tpv*) have a maximum K/Ar age of 8.39±0.36 m.y. (unpublished University of Utah Research Institute (UURI) K/Ar data, Evans and Foley, analysts) and a minimum age of 3.88±0.06 m.y.

Table 1. Radiometric (K/Ar) ages for selected rocks of the Belknap-Foley area

Sample no.*	Location	Rock type	Age**	Stratigraphic unit
MS-254	122°07'30" 44°14'10"	Basalt	w19.91±1.94 m.y.	Tmv
MS-253	122°12'40" 44°12'45"	Andesite	w8.46±0.11 m.y.	Tmv
MS-130	122°06'07" 44°13'10"	Basalt	w6.2±0.2 m.y.	Tmv
MS-17	122°02'00" 44°12'13"	Andesite	w6.2±0.2 m.y.	Tmv
A-20	122°02'38" 44°16'39"	Basaltic andesite Ash-flow tuff	w5.3±0.2 m.y.	Tpv
MS-205	122°02'55" 44°09'30"	Basaltic andesite	w5.06±0.06 m.y.	QTv
MS-208	122°06'30" 44°13'00"	Basaltic andesite	w3.88±0.06 m.y.	Tpv
MS-132 MS-110	122°00'50" 44°11'46"	Olivine basalt	w2.6±6.2 m.y. w2.1±0.1 m.y.	QTv
A-77	122°00'48" 44°17'00"	Basaltic andesite	w0.68±0.04 m.y.	QTv
U-Cougar	122°14'10" 44°07'46"	Basaltic andesite	p16.3±1.8 m.y.	Tmvi
U-RI-112	122°16'59" 44°06'30"	Andesite	p11.5±0.5 m.y.	Tmv
U-RI-85	122°16'10" 44°07'41"	Dacitic ash-flow tuff	p13.9±0.8 m.y.	Tmv
U-Foley	122°10'29" 44°10'49"	Basalt	w2.05±0.52 m.y.	QTv
U-Tmw-Top	122°11'49" 44°12'11"	Andesite	w8.93±0.34 m.y.	Tmv
U-Tpb	122°11'31" 44°12'32"	Basaltic andesite	w8.39±0.36 m.y.	Tpv
U-BF-5	122°12'30" 44°08'45"	Dacite	w9.31±0.44 m.y.	Tmdc

* References: MS - McBirney and others, 1974; A - Armstrong and others, 1975; U - Unpublished K/Ar data, University of Utah Research Institute, Stanley Evans and Duncan Foley, analysts.
** w = whole rock date; p = plagioclase date.

Table 2. Bulk chemical composition of selected rocks of Belknap-Foley area. (Letters at top of each column indicate sample number and map symbol for stratigraphic unit. All values are in weight percent.)

Component	*T-6 Qbh	J-2 Qtv	J-4 Qtv	J-3 Qtv	S-13 Tmv?	S-16 Tmv	P-7 Tmv?
SiO_2	47.0	47.8	48.38	49.80	53.00	53.0	54.25
TiO_2	-	1.63	2.19	1.68	1.10	1.20	1.28
Al_2O_3	-	15.42	15.47	15.42	18.30	18.80	16.46
Fe_2O_3	-	1.70	1.83	2.20	7.80 (Fe₂O₃ + FeO)	8.20	3.08
FeO	-	9.54	10.36	9.08			5.92
Mno	-	0.21	0.20	0.21	-	-	0.13
MgO	-	4.43	5.80	4.17	5.20	5.90	4.46
CaO	-	10.20	8.21	9.88	8.80	9.30	8.79
Na_2O	-	3.50	3.60	3.90	3.80	3.10	3.46
K_2O	-	1.30	0.64	1.25	0.40	0.25	0.80
P_2O_5	-	0.02	0.43	0.15	-	-	0.23
H_2O	-	1.36	1.39	0.86	-	-	1.58
Total	47.0	97.11	98.50	98.60	98.40	99.75	100.44

Component	S-15 Tmv	S-14 Tmv?	S-9 Tmv	S-12 Tmv	S-9 Tmv	S-10 Tov?	S-17 Tov?
SiO_2	54.30	54.70	55.80	57.20	58.00	60.90	61.20
TiO_2	1.10	1.10	1.10	0.95	1.00	1.10	1.55
Al_2O_3	18.80	17.80	18.50	18.20	16.40	17.40	15.20
F_2O_3 / FeO	7.80	8.0	7.5	7.00	9.6	6.80	8.1
MnO	-	-	-	-	-	-	-
MgO	5.20	5.90	4.40	4.20	5.90	2.00	2.50
CaO	8.80	8.50	6.60	8.20	4.90	4.80	4.50
Na_2O	3.00	3.90	4.20	3.50	2.80	4.30	4.30
K_2O	0.15	0.25	1.70	0.40	0.35	1.20	2.00
P_2O_5	-	-	-	-	-	-	-
H_2O	-	-	-	-	-	-	-
Total	99.15	100.15	99.80	99.65	98.95	98.50	99.17

*References: P-from Peck, 1964; J-from Jan, 1967; T-from Taylor, 1967; S-from Storch, 1978.

(Sutter, 1978). The above units occur principally in the Western Cascades province, in the western part of the map (Plate I).

The eastern part of the study area is completely dominated by compact to diktytaxitic basaltic lavas of Quaternary age (units *QTv* and *Qbh* on Plate I). These rocks appear to partially fill in the High Cascade graben described by Allen (1966) and Taylor (1978, 1980). Foley Ridge is a tongue of these Quaternary lavas which filled an east-west-trending canyon cut across the western scarp of the graben about 2.0 m.y. ago (unpublished K/Ar age of 2.05 ± 0.52 m.y. by UURI, Evans and Duncan, analysts).

For this study, the Quaternary lavas were split into two units based on lithology and stratigraphic relationships. Lavas assigned to unit *QTv* (Pliocene to Pleistocene basalts of the High Cascades) occupy topographic depressions which are clearly related to the present geomorphic setting. Nearly identical rocks located at high elevations of the Western Cascades were assigned to unit *Tpv* because they occupied topography strongly reversed from the present landscape. K/Ar data, where available, tend to support this division. The *Qbh* unit (Pleistocene to Holocene basalts of the High Cascades) was identified by extreme freshness of the rock, presence of uneroded tumuli and flow structures on flow tops, obvious control by very youthful drainages, and position above various Quaternary units.

K/Ar dates of samples from units *QTv* and *Qbh* are sparse and of relatively low precision and accuracy, but enough are available to provide some age control. Poor precision and accuracy is caused by the relatively low content of K_2O and youthful age of these lavas, which cause very low percentages of radiogenic argon relative to atmospheric argon. The oldest K/Ar date in the area-- 2.6 ± 0.2 m.y.-- is for unit *QTv* (Laurson and Hammond, 1978); the youngest age is 2.05 ± 0.52 m.y. (UURI date previously cited). A single K/Ar date of

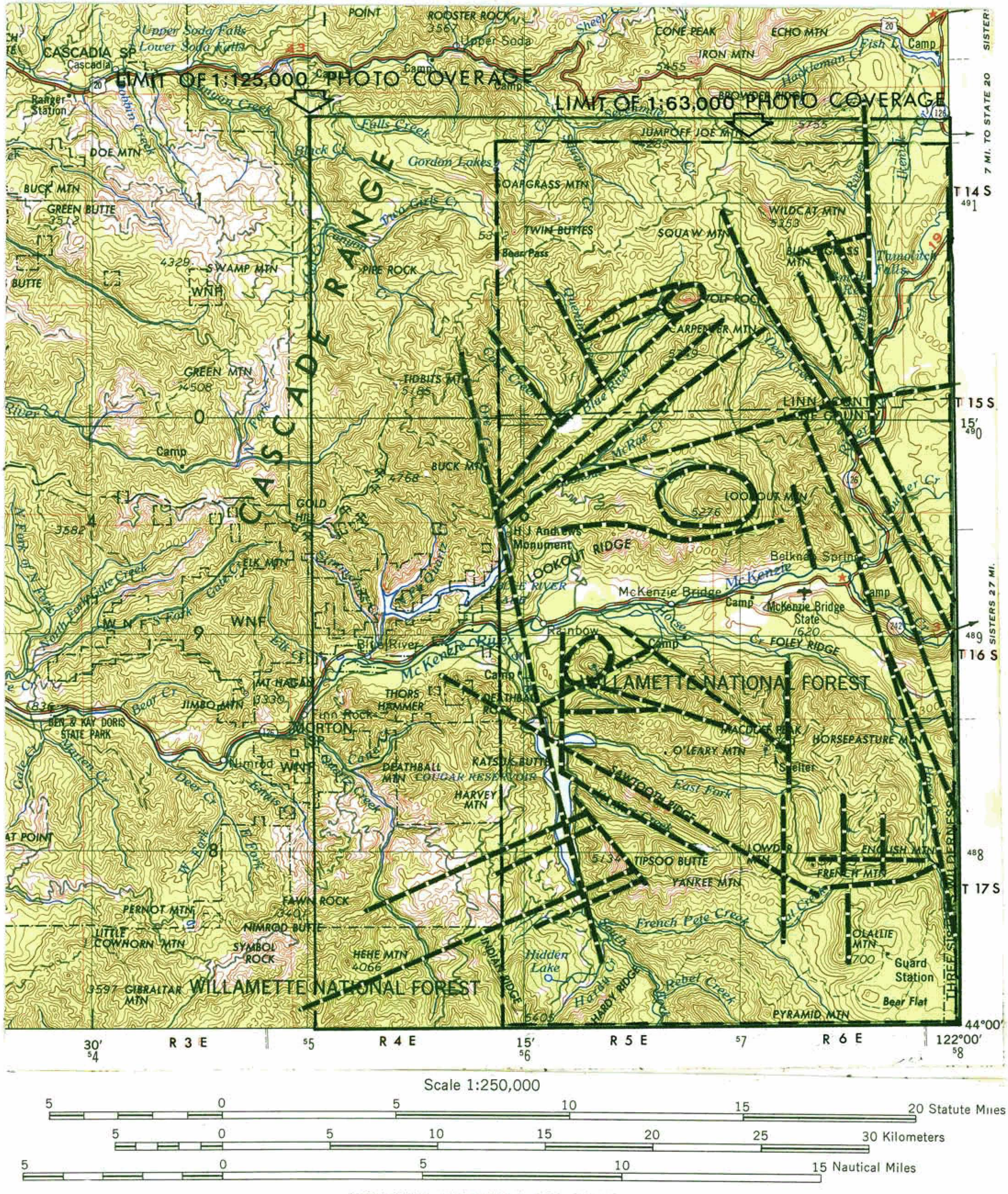
0.68 ± 0.05 m.y. was obtained from lavas mapped as unit *Qbh* (Laursen and Hammond, 1978).

Structural geology

Faults are concentrated in two major north-south-trending zones along Cougar Reservoir and along Horse Creek-McKenzie River. Both zones have en echelon north- to northwest-trending normal faults with significant dip-slip offsets down to the east. The lineament map (Figure 2) shows additional north-easterly trends along the northern margin of the area.

The Horse Creek-McKenzie River fault zone appears to define the western margin of a major north-south-trending graben which has been partially filled by a shield-like platform of late Pliocene and Quaternary High Cascades basaltic lavas and lesser andesitic ejecta (Allen, 1966; Taylor, 1978, 1980). The youngest dated unit with significant offset on the High Cascades graben margin is a 3.88-m.y.-old basaltic andesite (unit *Tpv*) on Frissel Point (Sutter, 1978), along the north fork of the McKenzie River. The capping lavas (unit *Tpv*) west of the north fork of the McKenzie River (Plate I) have been dropped down about 900 m (3,000 ft) to the east along a series of north- to northwest-trending en echelon step faults, but the total structural relief on the graben could be much more than this (Taylor, 1980, personal communication). Only minor offsets appear to affect the Quaternary lavas (Plate I).

The Cougar Reservoir fault zone trend is parallel to the High Cascades graben margin and appears to have a similar sense of movement, with Miocene and Oligocene volcanic rocks appearing to be displaced down toward the east across the zone. Miocene volcanic rocks (unit *Tmv*) are the youngest units with proven offset in this zone.



SALEM, OREGON
1960
REVISED 1977
TOPOGRAPHIC-BATHYMETRIC

Figure 2. PHOTO-LINEAMENT MAP OF BELKNAP-FOLEY AREA

14

Relation of structures to geothermal systems

The distribution of hot springs in the area is related to the two major north-south-trending fault zones discussed previously. Terwilliger Hot Springs and Cougar Hot Springs are located along the Cougar Reservoir lineament, while Belknap, Foley, and Bigelow Hot Springs are located along the western margin of the High Cascade graben. Hot-spring orifices do not, in general, issue from fault zones but from joints in lavas near the faults.

Three hypotheses might explain the apparent relation of faults to hot springs:

1. Faults actively control location of hot springs by serving as conduits for circulation of thermal waters.
2. Faults serve as passive controls on the location of hot springs by creating major topographic lows which may fortuitously tap sporadic thermal aquifers.
3. Some combination of hypotheses one and two controls the distribution of hot springs.

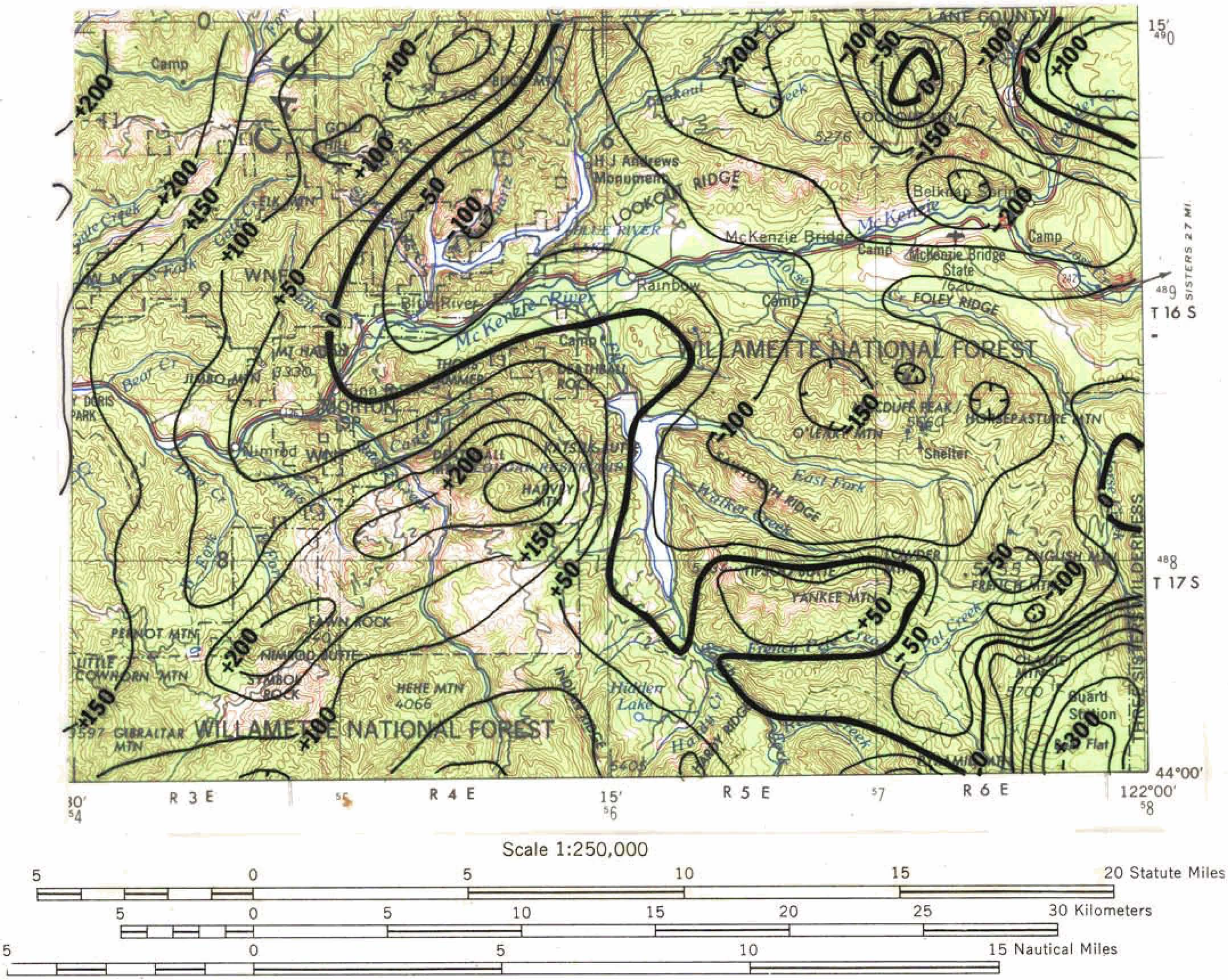
It is difficult to imagine that fault zones as large as those described here could have no influence on circulation of thermal waters. This is particularly true of the western margin of the High Cascade graben, where the faults are quite young and rocks of different lithology are juxtaposed across the faults. It is also true, however, that hot springs are more likely to issue from topographic lows created by fault-shatter zones, so that hypothesis three above is probably the most logical explanation for control of the hot springs.

GEOPHYSICS

Two geophysical studies were available for evaluation for this report. The first was a regional aeromagnetic study (Figure 3) performed by the Oregon State University Geophysics Group. This study, which is discussed in detail by Couch (1978) and Connard (1980), seems, in general, to show a close correspondence between magnetic maxima and topographic highs in the Belknap-Foley area. This is due to the fact that the Pliocene and Pleistocene units found capping the ridges tend to have a higher proportion of magnetically susceptible lavas than the older, underlying Miocene and Oligocene rocks.

Site-specific interpretations of the aeromagnetic data for the study area are not obvious. However, regional interpretation by Couch (1978) and Connard (1980) indicates a possible fault with east side down that is located in the approximate location of the Western Cascade-High Cascade transition zone fault mapped for this report (see section on geology) and that strikes in approximately the same trend. They also interpret the depth to the Curie point isotherm (temperature below which a material ceases to be paramagnetic; ~600^{o}C) to be greater on the west side of the fault than on the east side of the fault. This prediction matches well with Blackwell and others (1978), whose thermal model of the Cascades estimates a similar depth to the 600^{o}C isotherm.

The second geophysical study in this report is a regional gravity survey also performed by the Oregon State University Geophysics Group (Couch, 1978; Pitts, 1979). Their survey consists of a complete Bouguer gravity anomaly map (Figure 4) and a residual anomaly map (Figure 5), both of which are discussed in detail by Couch (1978) and Pitts (1979). The main feature of both these maps is the steep gravity gradient coincident with the High Cascades-Western Cascades transition zone and the location of local thermal



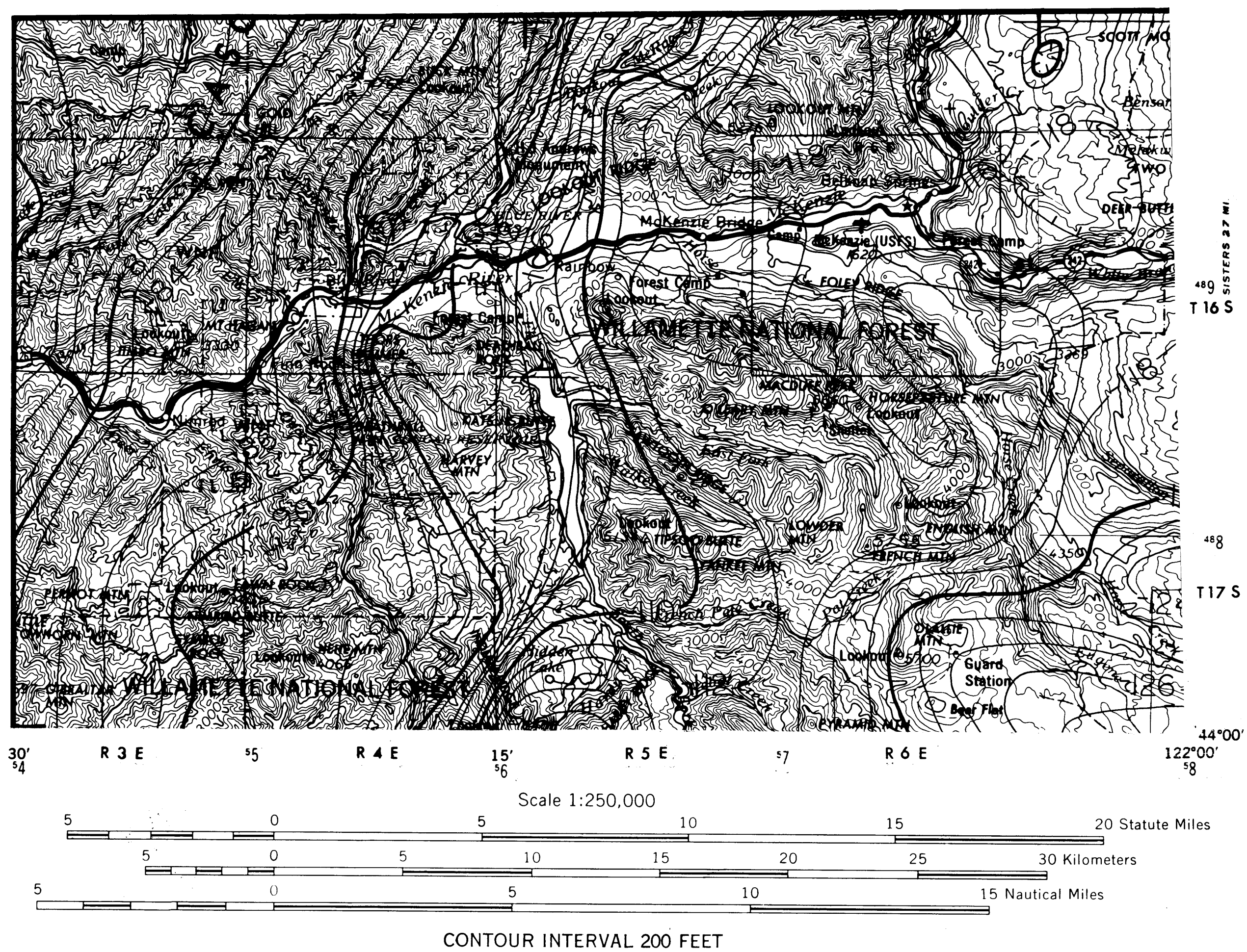
CONTOUR INTERVAL 200 FEET

SALEM, OREGON
1960
REVISED 1977

FIGURE 3. TOTAL FIELD AEROMAGNETIC ANOMALY MAP OF BELKNAP-FOLEY AREA

(From Connard, 1980) Contour interval 50 gammas

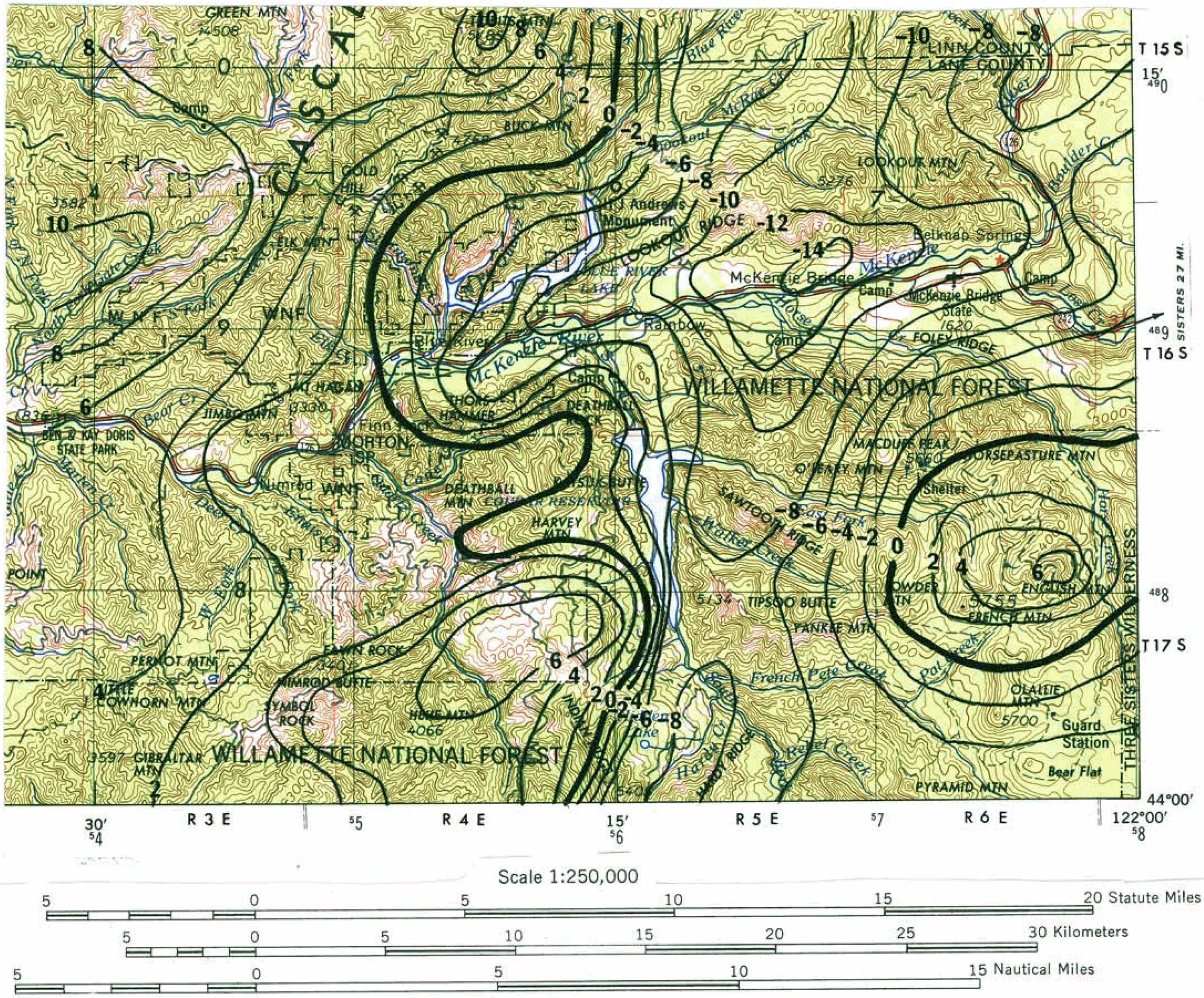
I.G.R.F. 1975
Data reference elevation 9,000 ft
Cutoff wavelength 15 km



SALEM, OREGON
1960
REVISED 1977

FIGURE 4. COMPLETE BOUGUER ANOMALY MAP OF BELKNAP-FOLEY AREA
(From Pitts and Couch, 1978) Contour interval 2.0 mgal

Estimated uncertainty 1.0 mgal
Reduction density 2.67 g/cm^3
Transverse Mercator Projection
Theoretical gravity: IGF (1930)



SALEM, OREGON

1960

REVISED 1977

Figure 5. RESIDUAL GRAVITY ANOMALY MAP OF BELKNAP-FOLEY AREA

(From Pitts, 1979) Contour interval 2.0 mgal

Estimated uncertainty 1.0 mgal
Reduction density 2.43 g/cm^3
Regional components greater than 895 km removed
Transverse Mercator Projection
Theoretical gravity: IGF (1930)

springs. Pitts (1979) interprets this anomaly to represent either a large graben-bounding fault zone with east side down, an area of shallow silicic intrusives, or a possible combination of both. Detailed geologic mapping and possibly deep drilling are needed to further refine geologic modeling based on the foregoing geophysical studies.

WATER CHEMISTRY

During this study, analyses were compiled of four of the five major thermal springs together with analyses of drill-hole waters in the Belknap-Foley area (Table 3). These data indicate that the thermal waters are generally an alkaline, sodium-chloride-rich carbonate water diagnostic of a hot-water-dominated system at depth with elevated reservoir temperatures (Table 4) calculated by methods presented in Appendix A. Preliminary evaluation of the available data indicates the springs may be placed in two groups. The first are the Bigelow, Belknap, and Foley springs, which show similar amounts of silica (60-110 mg/l), Na:K atomic ratios (54.1-78.5), and calculated minimum reservoir temperatures. Other similarities are seen by comparison of relative amounts of ions such as boron, fluoride, and chloride. The second group are those to the west including the Terwilliger spring cluster, Rider Creek and Walker Creek drill-hole waters (Table 3), and possibly the Cougar Reservoir spring, for which no analyses are available. These springs exhibit lower silica (14-50 mg/l), higher Na:K atomic ratios (80-107), lower amounts of chloride and lithium and higher amounts of sulfate ion, and lower calculated reservoir temperatures (Table 4).

Preliminary data are inconclusive at this point; however, the water group near Cougar Reservoir may represent either a dilute species of the springs to the east or a totally different species. Extensive sampling of thermal spring gases and local cold springs and analyses of all waters for isotopes is needed before a definitive study of the thermal regime can be made.

Table 3. Spring and well chemistry of the Belknap-Foley area. All measurements are in mg/l, except for pH or as indicated. nt = not tested; tr = trace.

	Belknap Springs	Belknap Springs	Belknap Springs	Belknap Springs (main)	Belknap Springs (east)
Location	16S/6E/11A	16S/6E/11A	16S/6E/11A	16S/6E/11A	16S/6E/11A
Date sampled	'03	'72	3/76	3/76	3/76
Temp. (^{o}C)	86.7	71	nt	89.0	66.0
pH	nt	7.62	nt	7.6	7.5
Conductance µmhos/cm	nt	4300	nt	3900	3720
Alkalinity X_h as mg/l HCO_3 X_c as mg/l $CaCO_3$	nt	nt	nt	14_c	16_c
Hardness as mg/l $CaCO_3$	nt	nt	nt	541	544
Total dissolved solids	2506	nt	2550	2491	2377
SiO_2	81	96	110	79.9	70.6
Na	364	690	630	525	490
K	69.0	15.0	17.0	16.8	15.2
Ca	455	210	210	208	198
Mg	13	0.2	0.29	0.3	0.4
Cl	1343	1300	1550	1195	1036
As	nt	0.35	nt	0.24	0.24
B	nt	6.4	3.6	7.6	7.1
Li	nt	0.95	1.3	1.04	0.95
F	nt	1.2	0.88	1.11	0.98
Fe (total)	nt	0.02	tr	0.1	0.1
Al	nt	nt	0.1	tr	tr
HCO_3	nt	17	nt	17	19
PO_4	nt	0.21	nt	0.27	0.41
SO_4	168	170	150	105	85
NO_3	nt	nt	nt	tr	0.08
NH_3	nt	nt	nt	0.19	0.15

Table 3. Spring and well chemistry of the Belknap-Foley area--Continued
All measurements are in mg/l, except for pH or as indicated. nt = not tested; tr = trace.

	Foley Springs	Bigelow Spring	Terwilliger Springs (upper)	Terwilliger Springs (lower)	Terwilliger Springs (upper)
Location	16S/6E/11A	15S/6E/26Ba	17S/5E/20Bb	17S/5E/20Bb	17S/5E/20Bb
Date sampled	3/76	3/76	'73	3/76	3/76
Temp. (^{o}C)	80.6	61.0	44.0	38.0	42.0
pH	8.0	7.8	7.7	8.4	8.2
Conductance µmhos/cm	4800	3800	2980	2830	2660
Alkalinity X_h as mg/l HCO_3 X_c as mg/l $CaCO_3$	13_c	18_c	nt	15_c	15_c
Hardness as mg/l $CACO_3$	1284	459	nt	557	484
Total dissolved solids	3333	2566	nt	1892	1763
SiO_2	60	69	50	46	47
Na	475	540	392	335	320
K	11	17	6.3	7.3	6.8
Ca	494	188	225	210	196
Mg	0.8	1	0.1	0.2	0.2
Cl	1304	1148	788	769	693
As	0.21	0.11	nt	0.1	0.1
B	10.0	6.5	5.1	6.4	6.2
Li	0.96	1.1	0.52	0.7	0.64
F	0.81	1.4	0.8	0.86	0.87
Fe (total)	tr	0.1	tr	0.1	0.1
Al	tr	tr	nt	tr	tr
HCO_3	nt	nt	19	nt	nt
PO_4	0.06	0.32	nt	0.08	0.08
SO_4	550	102	260	192	185
NO_3	tr	0.02	nt	0.01	tr
NH_3	0.15	0.39	nt	0.04	0.12

Table 3.Spring and well chemistry of the Belknap-Foley area--Continued. All measurements are in mg/l, except for pH or as indicated. nt = not tested; tr = trace.

Well or spring	Rider Creek Drill Hole	Walker Creek Drill Hole
Location	175/5E/20 Baa	175/5E/8Acd
Date Sampled	7/80	7/80
Temp. ^{o}C	18.5	15
Ph	7.77	7.37
Conductance umhos/cm	3400	810
Alkalinity		
Xh as mg/l HCO_3	nt	nt
Xc as mg/l $CaCO_3$	nt	nt
Hardness as mg/l $CaCO_3$	427.5	68.4
Total dissolved solids mg/l	1962	nt
SiO_2	14(?)	18(?)
Na	449	149
K	< 2.50	< 2.50
Ca	271	26
Mg	0.500	1
Cl	925	135
As	< 0.625	< 0.625
B	7.5	4.2
Li	0.49	< 0.050
F	0.9	0.2
FE (total)	0.12	0.29
Al	< 0.625	< 0.625
HCO_3	nt	nt
PO_4	nt	nt
SO_4	269	nt
NO_3	nt	nt
NH_4	< 0.1	0.6

Table 4. Geothermetric calculations* of minimum reservoir temperatures for selected thermal waters of the Belknap-Foley area

	Belknap Springs	Belknap Springs	Belknap Springs	Belknap Springs (Main)	Belknap Springs (East)	Terwilliger Springs (Lower)	Terwilliger Springs (Upper)
Flow rate liters/min.	284	300	~250	~250	~250	114	200
Measured temperature °C	86.7	71	NT	89	66	38	44
Na:K °C	226	87	97	107	104	87	74
Na:K:Ca 1/3 β °C	202	113	121	125	125	104	95
Na:K:Ca 4/3 β °C	110	82	85	83	83	52	48
Na:K:Ca Mg corrected °C	183	NC	NC	NC	NC	NC	NC
SiO_2 conductive	126	135	143	124	119	99	102
SiO_2 adiabatic °C	123	131	137	122	117	100	103
SiO_2 chalcedony °C	98	108	116	97	90	68	72
SiO_2 opal °C	7	15	23	179	164	-17	-14

*Methodology for calculations presented in Appendix A. NC = not calculated.

Table 4. Geothermetric calculations* of minimum reservoir temperatures for selected thermal waters of the Belknap-Foley area -- Continued

	Terwilliger Springs (Upper)	Bigelow Spring	Foley Spring	Ryder Creek Drill Hole	Walker Creek Drill Hole
Flow rate liters/min.	200	7.6	227	pumped	pumped
Measured temperature °C	42	61	80.6	18.5	15
Na:K °C	86	104	91	34	76
Na:K:Ca 1/3 β °C	103	125	106	61	97
Na:K:Ca 4/3 β °C	51	85	52	23	54
Na:K:Ca Mg corrected °C	NC	120	NC	NC	NC
SiO_2 conductive °C	99	117	111	NC	NC
SiO_2 adiabatic °C	100	116	110	NC	NC
SiO_2 chalcedony	69	89	82	NC	NC
SiO_2 opal °C	-16	-1	-6	NC	NC

*Methodology for calculations presented in Appendix A. NC = not calculated.

GEOTHERMAL-GRADIENT AND HEAT-FLOW DATA*

The temperature-gradient and heat-flow results for the Belknap-Foley area are as shown in Table 5. Included in the table are the township/range-section and latitude and longitude location of each hole. In addition, the hole name, date of logging used, and collar elevation are included for each hole. The bottom hole temperature, maximum depth, corrected temperature gradient, and, where available, corrected heat flow are printed in blue on Plate I. These values are also listed in the table, as are the depth interval and average thermal conductivity used for calculation of the gradient and heat flow. The values are given in SI units. To transform units, the following conversion factors were used: 1×10^{-6} cal/cm^2 sec (HFU) = 41.84 mWm^{-2}, 1×10^{-3} cal/cm sec^{o}C (TCU) = 0.4184 Wm^{-1}K^{-1}, and 1^{o}C/km = 1 mKm^{-1} = 18.2^{o}F/100 ft. Corrected gradient and corrected heat flow are values for which the topographic effects have been removed. These are significant for many of the sites studied.

The holes are ranked in terms of the quality of the gradient or heat-flow information: high quality (A), good quality (B), marginal quality (C), data with some problems (D), and data for which no useful temperature gradient or heat flow can be estimated (X). All thermal-conductivity measurements were made on cutting samples. Most of the holes shown on the table were drilled specifically for heat-flow studies, and the data quality is relatively high. In general, holes drilled in the Western Cascade rocks give linear gradients below near-surface effects that may vary in depth from 20 to 100 m. Holes 50-150 m deep in High Cascade rocks, such as 15S/6E-11Dc, are often isothermal because of lateral flow of water in the porous young volcanic rocks.

*By D. D. Blackwell, Southern Methodist University, Dallas, Texas.

Table 5. Geothermal-gradient data, Belknap-Foley area, Oregon

Twn/Rng-Section	N Lat. Deg.Min.	W Long Deg.Min.	Hole # Date	Collar Elev.	Bottom Temp. (°C)	Depth Interval (m)	Avg. TC $Wm^{-1}K^{-1}$	# TC	Uncorr. Gradient °C/km	Corr. Gradient °C/km	Corr. HF mWm^{-2}	Q HF
14S/ 6E- 32DC	44-18.20	122- 7.26	WOLF MDW 8/ 1/80	999	10.12	45.0 154.0	1.46	9	90.2 1.8	75.6	110	B
15S/ 6E- 11DC	44-16.10	122- 3.25	CR-TBR 7/26/77	716	75.20	.0 52.0						X
16S/ 6E- 2CA	44-12.13	122- 2.97	CR-FP 8/ 5/76	70	14.56	100.0 150.0	1.74 .03	11	84.1 1.4	88.3	154	C
16S/ 4E- 14DBB	44-10.05	122-17.50	BH-3Z 11/26/75	457	10.76	12.5 45.0	1.80 .33		37.8 .4	35.0	63	D
16S/ 5E- 30AAB	44- 9.31	122-14.62	ST DAM 2 8/ 8/79	389	11.74	25.0 61.0	1.32	1	56.3 1.2	53.0	70	C
16S/ 5E- 30ABB	44- 9.29	122-14.88	ST DAM 3 8/ 8/79	368	14.16	15.0 85.0	1.33	4	54.0	51.0	68	D
16S/ 5E- 30ABC	44- 9.13	122-14.98	ST DAM 1 8/ 8/79	368	12.91	45.0 79.7			50.8 3.6	48.0		C
16S/ 6E- 27BB	44- 9.06	122- 4.69	CR-HC 9/29/76	573	21.56	30.0 150.0	1.57 .05	12	96.2 .9	70.9	111	B
17S/ 5E- 8ACD	44- 6.39	122-13.99	WLKR CRK 7/24/80	585	15.78	105.0 155.0	(1.59)		54.1 .7	52.0	83	B
17S/ 5E- 20BAA	44- 4.90	122-13.84	RIDR CRK 7/31/80	536	24.77	60.0 154.0	1.64 .04	4	128.5 3.6	97.5	159	B
17S/ 6E- 25AD	44- 3.94	122- 1.37	MOSQ CRK 8/ 1/80	1005	11.06	115.0 152.0	1.55	3	62.8 1.4	73.8	114	C
18S/ 5E- 11BD	44- 1.12	122- 9.81	REBL CRK 7/31/80	780	14.40	55.0 155.0	1.55	3				X

Only one anomalous value is present, and in general the data fall into two groups: those east of the High Cascade-Western Cascade thermal boundary and those west of the boundary. West of the boundary, heat-flow values generally are below 55 mWm^{-2}, while east of the boundary they are generally above 100 mWm^{-2} (Blackwell and others, 1978). Typical gradients are 25-35°C/km and 60-70°C/km, respectively. The hole with the highest heat-flow value, at Rider Creek, was drilled within half a mile of Terwilliger Hot Springs, indicating that a slightly larger area is associated with the hot springs than is in evidence from the surface manifestations. Obviously, the value itself is biased by its proximity to the hot springs and cannot be considered a regional value.

CONCLUSIONS AND RECOMMENDATIONS

During the course of this investigation, two major north-south lineaments were found to have close correlation with the distribution of thermal springs and areas of increased heat-flow. Geological mapping revealed that both lineaments are the result of major north-south-trending fault zones and that these fault zones must, to a certain extent, control the flow of geothermal waters.

The available analyses indicate that the thermal waters may be separated into two compositional groups based on total ionic content, ionic ratios, and calculated reservoir temperatures. These two groups show a one-to-one correlation with the aforementioned fault zones: the hotter springs (i.e., Bigelow, Belknap, and Foley) being associated with the McKenzie-Horse Creek fault zone which forms the western margin of the High Cascade graben; and the cooler springs (Cougar and Terwilliger) being associated with the Cougar Reservoir fault zone which lies west of the High Cascade graben margin. This correlation is also seen in heat-flow measurements, with the higher values associated with the McKenzie-Horse Creek fault zone and the lower numbers associated with the Cougar Reservoir fault zone.

This preliminary data analysis indicates that the McKenzie-Horse Creek fault zone may control a higher temperature geothermal resource than the Cougar Reservoir fault zone. Both zones, however, contain geothermal resources which warrant further study. To accomplish a detailed assessment of the geothermal resources, the following steps are recommended:

1. Detailed mapping (scale of 1:24,000 or greater) of the McKenzie-Horse Creek fault zone making use of existing 1:15,000 U. S. Forest Service color aerial imagery -- to identify and evaluate active thermal structures along this zone.
2. Detailed spring and well sampling and analyses of both hot and cool waters, including isotopic and gas analyses -- to help evaluate reservoir conditions.

3. Closely spaced complete Bouguer and residual gravity anomaly studies along the fault zones -- to further refine the gravity anomalies found during previous regional studies and to tie anomalies to mapped structures.
4. Resistivity traverses (either dipole-dipole, roving dipole, or telluric) east-west and north-south along the fault zones -- to further define geothermal aquifers and to locate areas of thermal upwelling and recharge.
5. A program of five to ten 500-ft gradient/stratigraphy holes placed at strategic locations -- to refine the evaluation of the Belknap-Foley heat-flow model.
6. Five to six 2,000-ft gradient/stratigraphy holes -- to evaluate thermal anomalies and to directly test geothermal aquifers indicated by resistivity traverses and the shallow heat-flow study.
7. Feasibility study -- to determine the best method for drilling the very young, loosely consolidated volcanic rocks within the High Cascade graben.

BIBLIOGRAPHY OF THE BELKNAP-FOLEY AREA

Allen, J.E., 1966, The Cascade Range volcano-tectonic depression of Oregon, in Transactions, Lunar Geological Field Conference, Bend, Oregon, August 1965: Oregon Department of Geology and Mineral Industries, p. 21-23.

Armstrong, R.L., Taylor, E.M., Hales, P.O., and Parker, D.J., 1975, K-Ar dates for volcanic rocks, central Cascade Range of Oregon: Isochron/West, no. 13, p. 5-10.

Baldwin, E.M., 1976, Geology of Oregon (revised ed.): Dubuque, Iowa, Kendall/Hunt, 147 p.

Barnes, C.G., and Ritchey, J.L., 1978, Tectonic implications of structural patterns in the Cascades of southern Oregon (abs.): Proceedings of the Oregon Academy of Science, v. 14, p. 141-142.

Beaulieu, J.D., 1971, Geologic formations of western Oregon (west of longitude 121° 30'): Oregon Department of Geology and Mineral Industries Bulletin 70, 72 p.

Benson, G.T., 1965, The age of Clear Lake, Oregon: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 27, no. 2, p. 37-40.

Blackwell, D.D., 1969, Heat flow determinations in the northwestern United States: Journal of Geophysical Research, v. 74, no. 4, p. 992-1007.

Blackwell, D.D., Hull, D.A., Bowen, R.G., and Steele, J.L., 1978, Heat flow of Oregon: Oregon Department of Geology and Mineral Industries Special Paper 4, 42 p.

Blackwell, D.D., Steele, J.L., and Riccio, J.F., 1979, Heat flow of the Oregon Cascade Range (abs.): EOS (American Geophysical Union Transactions), v. 60, no. 46, p. 960.

Bodvarsson, G., Couch, R.W., MacFarlane, W.T., Tank, R.W., and Whitsett, R.M., 1974, Telluric current exploration for geothermal anomalies in Oregon: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 36, no. 6, p. 93-107.

Bogue, R.G., and Hodge, E.T., 1940, Cascade andesites of Oregon: American Mineralogist, v. 25, no. 10, p. 627-665.

Bowen, R.G., 1972, Geothermal gradient studies in Oregon: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 34, no. 4, p. 68-71.

_____ 1975, Geothermal gradient data: Oregon Department of Geology and Mineral Industries Open-File Report O-75-3, 133 p.

Bowen, R.G., and Blackwell, D.D., 1973, Progress report on geothermal measurements in Oregon: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 35, no. 1, p. 6-7.

Bowen, R.G., Blackwell, D.D., and Hull, D.A., 1975, Geothermal studies and exploration in Oregon (draft final report to U.S. Bureau of Mines): Oregon Department of Geology and Mineral Industries Open-File Report O-75-7, 65 p.

_____ 1977, Geothermal exploration studies in Oregon: Oregon Department of Geology and Mineral Industries Miscellaneous Paper 19, 50 p.

Bowen, R.G., and Peterson, N.V., compilers, 1970, Thermal springs and wells in Oregon: Oregon Department of Geology and Mineral Industries Miscellaneous Paper 14 (map), scale approx. 1:1,000,000.

Bowen, R.G., Peterson, N.V., and Riccio, J.F., compilers, 1978, Low- to intermediate-temperature thermal springs and wells in Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-10, scale 1:1,000,000.

Brooks, H.L., and Ramp, L., 1968, Gold and silver in Oregon: Oregon Department of Geology and Mineral Industries Bulletin 61, 337 p.

Brown, R.E., 1941, The geology and petrography of the Mount Washington area, Oregon: New Haven, Conn., Yale University master's thesis, 48 p.

Buddington, A.F., and Callaghan, E., 1936, Dioritic intrusive rocks and contact metamorphism in the Cascade Range in Oregon: American Journal of Science, 5th ser., v. 31, no. 186, p. 421-449.

Callaghan, E., 1933, Some features of the volcanic sequence in the Cascade Range in Oregon: American Geophysical Union Transactions, 14th Annual meeting, p. 243-249.

_____ 1934, Some aspects of the geology of the Cascade Range in Oregon (abs.): Washington Academy of Science Journal, v. 24, no. 4, p. 190-191.

Callaghan, E., and Buddington, A.F., 1938, Metalliferous mineral deposits of the Cascade Range in Oregon: U.S. Geological Survey Bulletin 893, 141 p.

Campbell, I., 1925, A geologic reconnaissance of the McKenzie River section of the Oregon Cascades with petrographic descriptions of some of the more important rock types: Eugene, Oreg., University of Oregon master's thesis, 56 p.

Connard, G.G., 1980, Analysis of aeromagnetic measurements from the central Oregon Cascades: Corvallis, Oreg., Oregon State University master's thesis, 101 p.

Connard, G.G., Couch, R.W., and Gemperle, M., 1979, Regional tectonic and thermal model of the central Cascades, Oregon, from magnetic data (abs.): EOS (American Geophysical Union Transactions), v. 60, no. 46, p. 959.

Connard, G.G., Gemperle, M., and Couch, R.W., 1978, A new aeromagnetic anomaly map of the central Cascades region of Oregon (abs.): EOS (American Geophysical Union Transactions), 25th Pacific N.W. Region meeting, Tacoma, Wash. (unpublished).

Couch, R.W., 1978, Geophysical investigations of the Cascade Range in central Oregon: U.S. Geological Survey Extramural Geothermal Research Program, Technical Report 4 (unpublished), 133 p.

Couch, R.W., and Baker, B., 1977, Geophysical investigations of the Cascade Range in central Oregon: U.S. Geological Survey Extramural Geothermal Research Program, Technical Report 2 (unpublished), 55 p.

Couch, R.W., Gemperle, M., and Connard, G.G., 1978, Total field aeromagnetic anomaly map, Cascade Mountain Range, central Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-9, scale 1:125,000.

Dickinson, W.R., 1979, Cenozoic plate tectonic setting of the Cordilleran region in the United States, in Armentrout, J.M., Cole, M.R., and Terbest, H., Jr., eds., Cenozoic paleogeography of the western United States: Pacific Coast Paleogeography Symposium 3, Anaheim, Calif., March 15-16, 1979, p. 1-13.

Dole, H.M., ed., 1968, Andesite Conference guidebook: Oregon Department of Geology and Mineral Industries Bulletin 62, 107 p.

Godwin, L.H., Haigler, L.B., Rioux, R.L., White, D.E., Muffler, L.J.P., and Wayland, R.G., 1971, Classification of public lands valuable for geothermal steam and associated geothermal resources: U.S. Geological Survey Circular 647, 18 p.

Greene, R.C., 1968, Petrography and petrology of volcanic rocks in the Mount Jefferson area, High Cascade Range, Oregon: U.S. Geological Survey Bulletin 1251-G, 48 p.

Groh, E.A., 1966, Geothermal energy potential in Oregon: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 28, no. 7, p. 125-135.

Hammond, P.E., 1974, Brief outline to volcanic stratigraphy and guide to geology of southern Cascade Range, Washington, and northern Cascade Range, Oregon: Oregon Department of Geology and Mineral Industries unpublished report, 51 p.

_____ 1976, Geothermal model for the Cascade Range: Oregon Department of Geology and Mineral Industries unpublished report, 20 p.

_____ 1979, A tectonic model for evolution of the Cascade Range, in Armentrout, J.M., Cole, M.R., and Terbest, H., Jr., eds., Cenozoic paleogeography of the western United States: Pacific Coast Paleogeography Symposium 3, Anaheim, Calif., March 15-16, 1979, p. 219-237.

Hodge, E.T., 1925, Mount Multnomah, ancient ancestor of the Three Sisters: Eugene, Oreg., University of Oregon Publication, v. 3, no. 2, 160 p.

_____ 1928, Framework of Cascade Mountains in Oregon: Pan-American Geologist, v. 49, no. 5, p. 341-356.

_____ 1931, Geologic map of north central Oregon: Eugene, Oreg., University of Oregon Publication, Geology Series, v. 1, no. 5, scale 1:250,000.

Hull, D.A., Blackwell, D.D., and Black, G.L., 1978, Geothermal gradient data: Oregon Department of Geology and Mineral Industries Open-File Report O-78-4, 187 p.

Hull, D.A., Bowen, R.G., Blackwell, D.D., and Peterson, N.V., 1977, Preliminary heat-flow map and evaluation of Oregon's geothermal energy potential: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 39, no. 7, p. 109-123.

Jan, M.Q., 1967, Geology of the McKenzie River valley between the South Santiam Highway and the McKenzie Pass Highway, Oregon: Eugene, Oreg., University of Oregon master's thesis, 70 p.

Kittleman, L.R., 1973, Mineralogy, correlation, and grain-size distributions of Mazama tephra and other postglacial pyroclastic layers, Pacific Northwest: Geological Society of America Bulletin, v. 84, no. 9, p. 2957-2980.

Laursen, J. M., and Hammond, P. E., 1978, Summary of radiometric ages of Oregon rocks--supplement 1: July 1972 through December 1976: Isochron/West, no. 23, p. 3-28.

Lawrence, R.D., 1976, Strike-slip faulting terminates the Basin and Range province in Oregon: Geological Society of America Bulletin, v. 87, no. 6, p. 846-850.

Mackin, J.H., and Cary, A.S., 1965, Origin of Cascade landscapes: Washington Division of Mines and Geology Information Circular 41, 35 p.

Mariner, R.H., Presser, T.S., Rapp, J.B., and Willey, L.M., 1975, The minor and trace elements, gas, and isotope compositions of the principal hot springs of Nevada and Oregon: U.S. Geological Survey open-file report, 27 p.

Mariner, R.H., Rapp, J.B., Willey, L.M., and Presser, T.S., 1974, The chemical composition and estimated minimum thermal reservoir temperatures of selected hot springs in Oregon: U.S. Geological Survey open-file report, 27 p.

Mariner, R.H., Swanson, J.R., Orris, G.J., Presser, T.S., and Evans, W.C., 1980, Chemical and isotopic data for water from thermal springs and wells of Oregon: U.S. Geological Survey Open-File Report 80-737, 50 p.

McBirney, A.R., 1968, Petrochemistry of the Cascade andesite volcanoes, in Dole, H.M., ed., Andesite Conference guidebook: Oregon Department of Geology and Mineral Industries Bulletin 62, p. 101-107.

_____ 1975, Consequences of recent stratigraphic studies in the Oregon Cascade Range (abs.): Proceedings of the Oregon Academy of Science, v. 11, p. 83.

McBirney, A.R., 1976, Some geologic constraints on models for magma generation in orogenic environments: Canadian Mineralogist, v. 14, no. 3, p. 245-254.

McBirney, A.R., Sutter, J.F., Naslund, H.R., Sutton, K.G., and White, C.M., 1974, Episodic volcanism in the central Oregon Cascade Range: Geology, v. 2, no. 12, p. 585-589.

McBirney, A.R., and White, C.M., 1977, Some quantitative aspects of orogenic volcanism in the Oregon Cascades (abs.): Geological Society of America Abstracts with Programs, v. 9, no. 7, p. 1087.

_____ 1978, Recent progress in studies of the Oregon Cascades (abs.): Proceedings of the Oregon Academy of Science, v. 14, p. 157-158.

Muffler, L.J.P., ed., 1979, Assessment of geothermal resources of the United States--1978: U.S. Geological Survey Circular 790, 163 p.

Peck, D.L., Griggs, A.B., Schlicker, H.G., Wells, F.G., and Dole, H.M., 1964, Geology of the central and northern parts of the Western Cascade Range in Oregon: U.S. Geological Survey Professional Paper 449, 56 p.

Peterson, N.V., and Groh, E.A., eds, 1965, Lunar Geological Field Conference guidebook: Oregon Department of Geology and Mineral Industries Bulletin 57, 51 p.

Peterson, N.V., and Youngquist, W., 1975, Central Western and High Cascades geological reconnaissance and heat flow hole location recommendations: Oregon Department of Geology and Mineral Industries Open-File Report 0-75-2, 41 p.

Pitts, G.S., 1979, Interpretation of gravity measurements made in the Cascade Mountains and the adjoining Basin and Range province in central Oregon: Corvallis, Oreg., Oregon State University master's thesis, 186 p.

Pitts, G.S., Connard, G.G., Gemperle, M., and Couch, R.W., 1978, Gravity and aeromagnetic measurements in the central Cascades of Oregon (abs.): EOS (American Geophysical Union Transactions), v. 59, no. 12, p. 1188-1189.

Pitts, G.S., and Couch, R.W., 1978, Complete Bouguer gravity anomaly map, Cascade Mountain Range, central Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-8, scale 1:125,000.

Riccio, J.F., compiler, 1979, Preliminary geothermal resource map of Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-11, scale 1:500,000.

_____ 1980, Geothermal exploration in Oregon, 1979: Oregon Department of Geology and Mineral Industries, Oregon Geology, v. 42, no. 4, p. 59-69.

Riccio, J.F., and Newton, V.C., Jr., 1979, Geothermal exploration in Oregon in 1978: Oregon Department of Geology and Mineral Industries, Oregon Geology, v. 41, no. 3, p. 39-46.

Sass, J.H., Lachenbruch, A.H., Munroe, R.J., Green, G.W., and Moses, T.H., Jr., 1971, Heat flow in the western United States: Journal of Geophysical Research, v. 76, no. 26, p. 6376-6413.

Stearns, H.T., 1928, Geology and water resources of the upper McKenzie valley, Oregon: U.S. Geological Survey Water-Supply Paper 597, p. 171-188.

Storch, S.G.P., 1978, Geology of the Blue River Mining District, Linn and Lane Counties, Oregon: Corvallis, Oreg., Oregon State University master's thesis, 70 p.

Sutter, J.F., 1978, K/Ar ages of Cenozoic volcanic rocks from the Oregon Cascades west of 121° 30': Isochron/West, no. 21, p. 15-31.

Swanson, F.J., and James, M.E., 1975a, Geology and geomorphology of the H.J. Andrews Experimental Forest, Western Cascades, Oregon: U.S. Department of Agriculture Forest Service Research Paper PNW-188, 14 p.

_____ 1975b, Geomorphic history of the lower Blue River-Lookout Creek area, Western Cascades, Oregon: Northwest Science, v. 49, no. 1, p. 1-11.

Taylor, E.M., 1965, Recent volcanism between Three Fingered Jack and North Sister, Oregon Cascade Range: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 27, no. 7, p. 121-147.

_____ 1967, Recent volcanism between Three Fingered Jack and North Sister, Oregon Cascade Range: Pullman, Wash., Washington State University doctoral dissertation, 84 p.

_____ 1968, Roadside geology, Santiam and McKenzie Pass Highways, Oregon, in Dole, H.M., ed., Andesite Conference guidebook: Oregon Department of Geology and Mineral Industries Bulletin 62, p. 1-33.

_____ 1978, Field geology of S.W. Broken Top quadrangle, Oregon: Oregon Department of Geology and Mineral Industries Special Paper 2, 50 p.

_____ 1980, Volcanic and volcaniclastic rocks on the east flank of the central Cascade Range to the Deschutes River, Oregon, in Oles, K.F., Johnson, J.G., Niem, A.R., and Niem, W.A., eds., Geologic field trips in western Oregon and southwestern Washington: Oregon Department of Geology and Mineral Industries Bulletin 101, p. 1-7.

Taylor, H.P., 1971, Oxygen isotope evidence for large-scale interaction between meteoric groundwaters and Tertiary granodiorite intrusions, Western Cascade Range, Oregon: Journal of Geophysical Research, v. 76, p. 7855-7874.

Thayer, T.P., 1937, Petrology of later Tertiary and Quaternary rocks of the north-central Cascade Mountains in Oregon, with notes on similar rocks in western Nevada: Geological Society of America Bulletin, v. 48, no. 11, p. 1611-1651.

Thiruvathukal, J.V., 1968, Regional gravity of Oregon: Corvallis, Oreg., Oregon State University doctoral dissertation, 92 p.

Tuck, R., 1927, The geology and ore deposits of the Blue River Mining District: Eugene, Oreg., University of Oregon master's thesis, 60 p.

U.S. Forest Service, 1979, Belknap-Foley geothermal area: Eugene, Oreg., U.S.D.A., Willamette National Forest, draft environmental statement for geothermal leasing 06-18-79-11, 224 p., supplement, 80 p.

U.S. Geological Survey and Oregon Department of Geology and Mineral Industries, 1979, Chemical analyses of thermal springs and wells in Oregon: Oregon Department of Geology and Mineral Industries Open-File Report O-79-3, 170 p.

Walker, G.W., Greene, R.C., and Pattee, E.C., 1966, Mineral resources of the Mount Jefferson primitive area, Oregon: U.S. Geological Survey Bulletin 1230-D, 32 p.

Wells, F.G., and Peck, D.L., 1961, Geologic map of Oregon west of the 121st meridian: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-325, scale 1:500,000.

Wheeler, H.E., and Mallory, V.S., 1970, Oregon Cascades in relation to Cenozoic stratigraphy, in Columbia River Basalt Symposium, 2nd, Cheney, Wash., 1969, Proceedings: Cheney, Wash., Eastern Washington State College Press, p. 97-124.

Wilkinson, W.D., and Schlicker, H.G., 1959, Field trip 3, Corvallis to Prineville via Bend and Newberry Crater, in Field guidebook: geologic trips along Oregon highways: Oregon Department of Geology and Mineral Industries Bulletin 50, p. 43-72.

Williams, H., 1944, Volcanoes of the Three Sisters region, Oregon Cascades: University of California, Department of Geological Sciences Bulletin, v. 27, no. 3, p. 37-83.

_____ 1953, The ancient volcanoes of Oregon (2d ed.): Eugene, Oreg., Oregon State System of Higher Education, Condon Lectures, 68 p.

_____ 1957, A geologic map of the Bend quadrangle, Oregon, and a reconnaissance geologic map of the central portion of the High Cascade Mountains: Oregon Department of Geology and Mineral Industries in cooperation with the U.S. Geological Survey, scales 1:125,000 and 1:250,000.

APPENDIX A

Formulas used in calculations

Na:K (revised):

$$t\ ^{o}C = \frac{1217}{\log\ (Na/K) + 1.483} - 273.15 \text{ (Fournier, 1979)}$$

Na:K:Ca:

$$t\ ^{o}C = \frac{1647}{2.24 + F\ (T)} - 273.15 \text{ (Fournier and Truesdell, 1973),}$$

where $F\ (T) = \log\ (Na/K) + [\ \beta \log\ (\sqrt{Ca}/Na)\ ]$,
β = 1/3 if t> 100^{o}C, and 4/3 if t <100^{o}C,
$t^{o}C$ = calculated reservoir temperature,
and concentrations are expressed in molality.

Magnesium correction ratio:

$$R = \frac{\text{(milliequivalents Mg)}}{\text{(milliequivalents Mg) + (milliequivalents Ca) + (milliequivalents K)}} \times 100$$

If R <5 or >50, no calculation was made. For R between 5-50,

$$\Delta t_{Mg} = 10.66-(4.7415)\ (R) + [(325.87)\ (\log R)^2] - [(1.032 \times 10^5)\ (\log R)^2/T] - [(1.968 \times 10^7)\ (\log R)^2/T^2] + [(1.605 \times 10^7)\ (\log R)^3/T^2],$$

where R = magnesium correction ratio expressed in equivalents,
Δt_{Mg} = the temperature correction that is subtracted from the Na:K:Ca 1/3 β calculated temperature,
T = Na:K:Ca 1/3 β calculated temperature in ^{o}K.

Or Δt_{Mg} can be obtained by using the graph compiled by Fournier and Potter (1979).

SiO_2 temperature calculations (Fournier and Rowe, 1966):

SiO_2 (conductive), $$t^{o}C = \frac{1309}{5.19 + \log\ (SiO_2)} - 273.15$$

SiO_2 (adiabatic), $$t^{o}C = \frac{1522}{5.75 + \log\ (SiO_2)} - 273.15$$

SiO_2 (chalcedony), $$t^{o}C = \frac{1032}{4.69 + \log\ (SiO_2)} - 273.15$$

SiO_2 (opal), $$t^{o}C = \frac{731}{4.52 + \log\ (SiO_2)} - 273.15,$$

where SiO_2 is expressed in mg/l.

References cited:

Fournier, R.O., 1979, A revised equation for the Na/K geothermometer, in Geothermal Resources Council Transactions 3, 1979, p. 221-224.

Fournier, R.O., and Potter, R.W., II, 1979, Magnesium correction to the Na:K:Ca chemical geothermometer: Geochimica et Cosmochimica Acta, v. 43, p. 1543-1550.

Fournier, R.O., and Rowe, J.J., 1966, Estimation of underground temperatures from the silica content of water from hot springs and wet-steam wells: American Journal of Science, v. 264, p. 685-697.

Fournier, R.O., and Truesdell, A.H., 1973, An empirical Na:K:Ca geothermometer for natural waters: Geochimica et Cosmochimica Acta, v. 37, p. 1255-1275.

Mariner, R.H., Swanson, J.R., Orris, G.J., Presser, T.S., and Evans, W.C., 1980, Chemical and isotopic data for water from thermal springs and wells of Oregon: U.S. Geological Survey Open-File Report 80-737, 50 p.

APPENDIX B

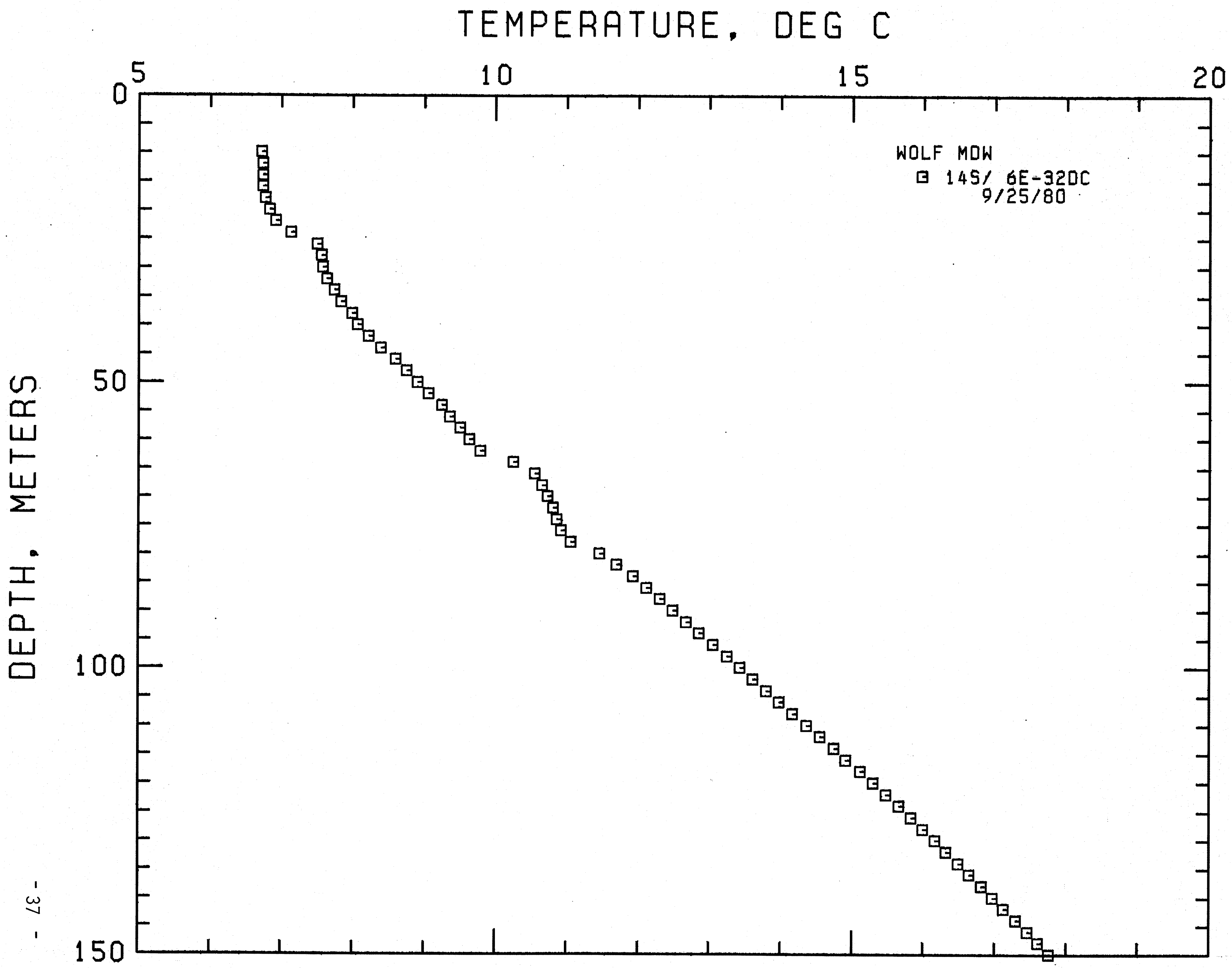
Geothermal-gradient data

LOCATION: SALEM AMS, OREGON
14S/ 6E-32DC
HOLE NAME: WOLF MDW
DATE MEASURED: 9/25/80

DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	TEMPERATURE DEG F	GEOTHERMAL GRADIENT DEG C/KM	GEOTHERMAL GRADIENT DEG F/100 FT
10.0	32.8	6.720	44.10	0.0	0.0
12.0	39.4	6.740	44.13	10.0	0.5
14.0	45.9	6.740	44.13	0.0	0.0
16.0	52.5	6.740	44.13	0.0	0.0
18.0	59.0	6.770	44.19	15.0	0.8
20.0	65.6	6.830	44.29	30.0	1.6
22.0	72.2	6.920	44.46	45.0	2.5
24.0	78.7	7.130	44.83	105.0	5.8
26.0	85.3	7.500	45.50	185.0	10.2
28.0	91.8	7.560	45.61	30.0	1.6
30.0	98.4	7.580	45.64	10.0	0.5
32.0	105.0	7.640	45.75	30.0	1.6
34.0	111.5	7.740	45.93	50.0	2.7
36.0	118.1	7.840	46.11	50.0	2.7
38.0	124.6	7.990	46.38	75.0	4.1
40.0	131.2	8.070	46.53	40.0	2.2
42.0	137.8	8.220	46.80	75.0	4.1
44.0	144.3	8.390	47.10	85.0	4.7
46.0	150.9	8.600	47.48	105.0	5.8
48.0	157.4	8.750	47.75	75.0	4.1
50.0	164.0	8.910	48.04	80.0	4.4
52.0	170.6	9.060	48.31	75.0	4.1
54.0	177.1	9.250	48.65	95.0	5.2
56.0	183.7	9.360	48.85	55.0	3.0
58.0	190.2	9.510	49.12	75.0	4.1
60.0	196.8	9.640	49.35	65.0	3.6
62.0	203.4	9.790	49.62	75.0	4.1
64.0	209.9	10.250	50.45	230.0	12.6
66.0	216.5	10.550	50.99	150.0	8.2
68.0	223.0	10.660	51.19	55.0	3.0
70.0	229.6	10.730	51.31	35.0	1.9
72.0	236.2	10.810	51.46	40.0	2.2
74.0	242.7	10.860	51.55	25.0	1.4
76.0	249.3	10.920	51.66	30.0	1.6
78.0	255.8	11.060	51.91	70.0	3.8
80.0	262.4	11.460	52.63	200.0	11.0
82.0	269.0	11.700	53.06	120.0	6.6
84.0	275.5	11.930	53.47	115.0	6.3
86.0	282.1	12.120	53.82	95.0	5.2
88.0	288.6	12.310	54.16	95.0	5.2
90.0	295.2	12.490	54.48	90.0	4.9

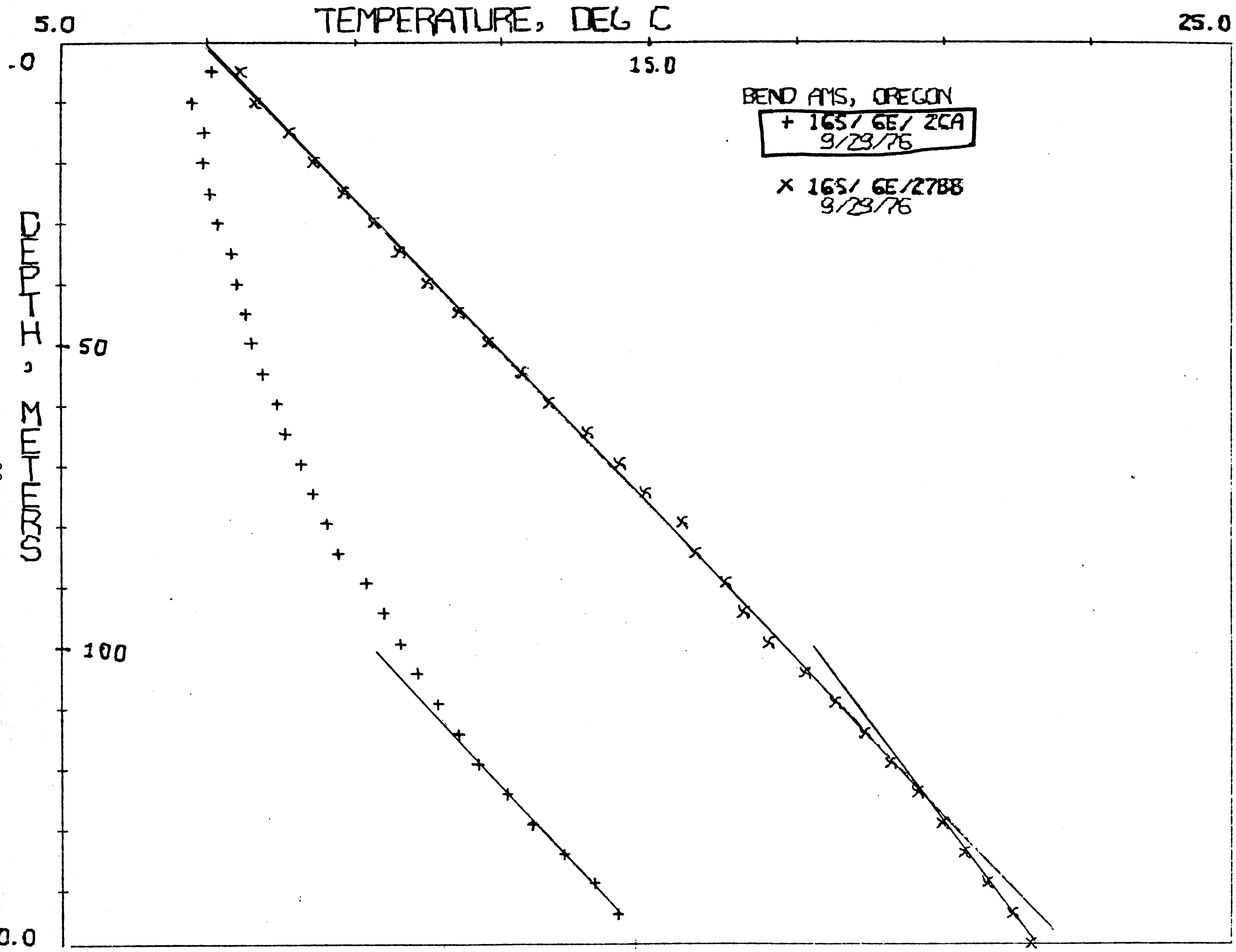
LOCATION: SALEM AMS, OREGON PAGE 2
14S/ 6E-32DC
HOLE NAME: WOLF MDW
DATE MEASURED: 9/25/80

DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	TEMPERATURE DEG F	GEOTHERMAL GRADIENT DEG C/KM	GEOTHERMAL GRADIENT DEG F/100 FT
92.0	301.8	12.680	54.82	95.0	5.2
94.0	308.3	12.860	55.15	90.0	4.9
96.0	314.9	13.060	55.51	100.0	5.5
98.0	321.4	13.250	55.85	95.0	5.2
100.0	328.0	13.430	56.17	90.0	4.9
102.0	334.6	13.610	56.50	90.0	4.9
104.0	341.1	13.800	56.84	95.0	5.2
106.0	347.7	13.980	57.16	90.0	4.9
108.0	354.2	14.170	57.51	95.0	5.2
110.0	360.8	14.370	57.87	100.0	5.5
112.0	367.4	14.560	58.21	95.0	5.2
114.0	373.9	14.750	58.55	95.0	5.2
116.0	380.5	14.920	58.86	85.0	4.7
118.0	387.0	15.120	59.22	100.0	5.5
120.0	393.6	15.300	59.54	90.0	4.9
122.0	400.2	15.480	59.86	90.0	4.9
124.0	406.7	15.660	60.19	90.0	4.9
126.0	413.3	15.830	60.49	85.0	4.7
128.0	419.8	16.000	60.80	85.0	4.7
130.0	426.4	16.170	61.11	85.0	4.7
132.0	433.0	16.320	61.38	75.0	4.1
134.0	439.5	16.490	61.68	85.0	4.7
136.0	446.1	16.650	61.97	80.0	4.4
138.0	452.6	16.820	62.28	85.0	4.7
140.0	459.2	16.970	62.55	75.0	4.1
142.0	465.8	17.130	62.83	80.0	4.4
144.0	472.3	17.300	63.14	85.0	4.7
146.0	478.9	17.460	63.43	80.0	4.4
148.0	485.4	17.610	63.70	75.0	4.1
150.0	492.0	17.760	63.97	75.0	4.1
152.0	498.6	17.910	64.24	75.0	4.1
154.0	505.1	18.040	64.47	65.0	3.6


TEMPERATURE, DEG C
5
10
15
20
0
50
100
150
DEPTH, METERS
WOLF MDW
14S/ 6E-32DC
9/25/80

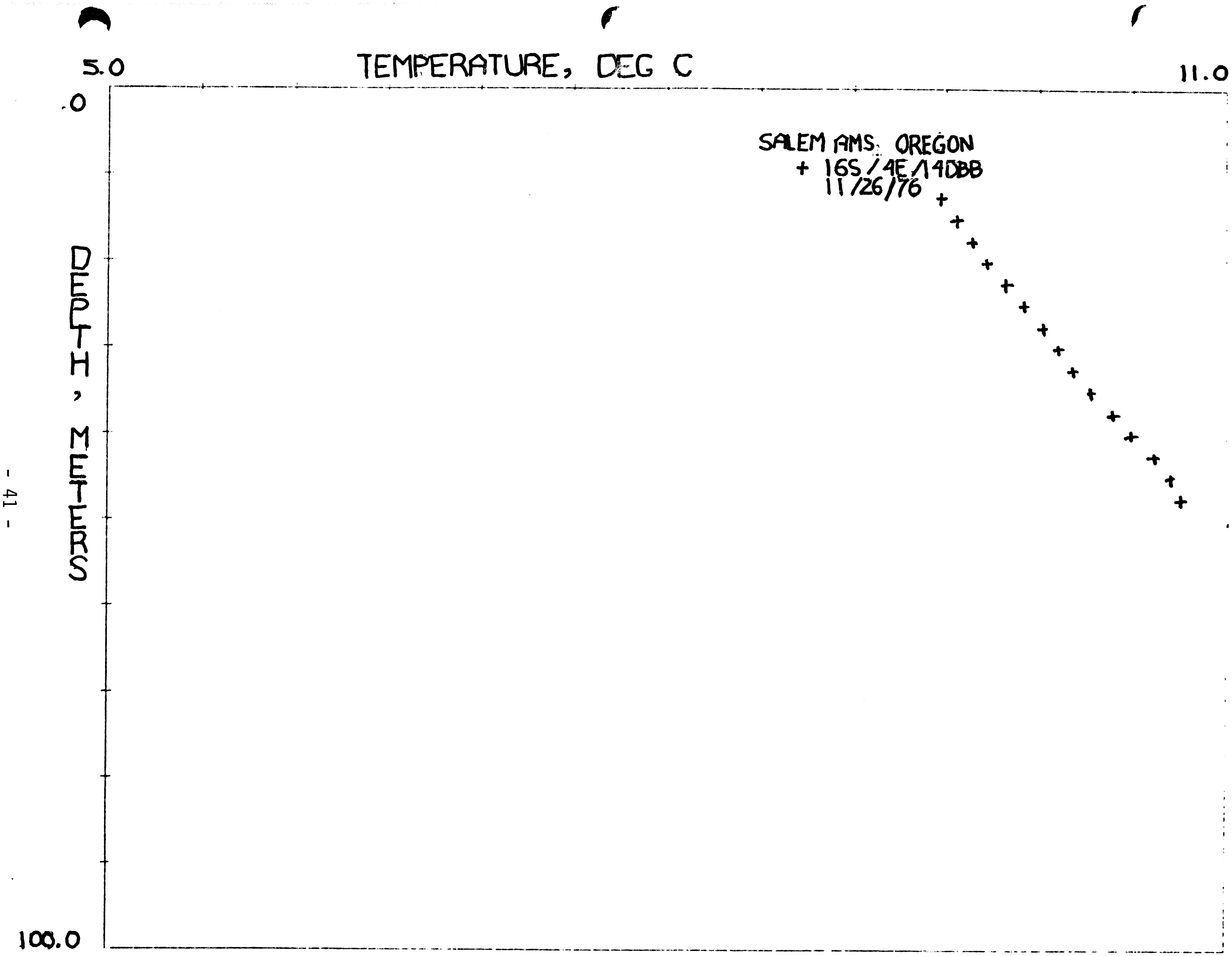
LOCATION: SALEM AMS, OREGON
16S/ 6E/ 2CA
HOLE NUMBER: CR-FP
DATE MEASURED: 9/29/76

DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	TEMPERATURE DEG F	GEOTHERMAL GRADIENT DEG C/KM	GEOTHERMAL GRADIENT DEG F/100 FT
5.0	16.4	7.600	45.68	.0	.0
10.0	32.8	7.270	45.09	-66.0	-3.6
15.0	49.2	7.470	45.45	40.0	2.2
20.0	65.6	7.440	45.39	-6.0	-.3
25.0	82.0	7.550	45.59	22.0	1.2
30.0	98.4	7.690	45.84	28.0	1.5
35.0	114.8	7.900	46.22	42.0	2.3
40.0	131.2	7.990	46.38	18.0	1.0
45.0	147.6	8.150	46.67	32.0	1.8
50.0	164.0	8.260	46.87	22.0	1.2
55.0	180.4	8.440	47.19	36.0	2.0
60.0	196.8	8.690	47.64	50.0	2.7
65.0	213.2	8.820	47.88	26.0	1.4
70.0	229.6	9.080	48.34	52.0	2.9
75.0	246.0	9.280	48.70	40.0	2.2
80.0	262.4	9.540	49.17	52.0	2.9
85.0	278.8	9.740	49.53	40.0	2.2
90.0	295.2	10.210	50.38	94.0	5.2
95.0	311.6	10.500	50.90	58.0	3.2
100.0	328.0	10.810	51.46	62.0	3.4
105.0	344.4	11.080	51.94	54.0	3.0
110.0	360.8	11.450	52.61	74.0	4.1
115.0	377.2	11.810	53.26	72.0	4.0
120.0	393.6	12.130	53.83	64.0	3.5
125.0	410.0	12.630	54.73	100.0	5.5
130.0	426.4	13.040	55.47	82.0	4.5
135.0	442.8	13.600	56.48	112.0	6.1
140.0	459.2	14.110	57.40	102.0	5.6
145.0	475.6	14.500	58.10	78.0	4.3
150.0	492.0	14.810	58.66	62.0	3.4


TEMPERATURE, DEG C
5.0
15.0
25.0
DEPTH, METERS
.0
50
100
150.0
BEND AMS, OREGON
+ 16S/ 6E/ 2CA
9/23/76
× 16S/ 6E/27BB
9/23/76

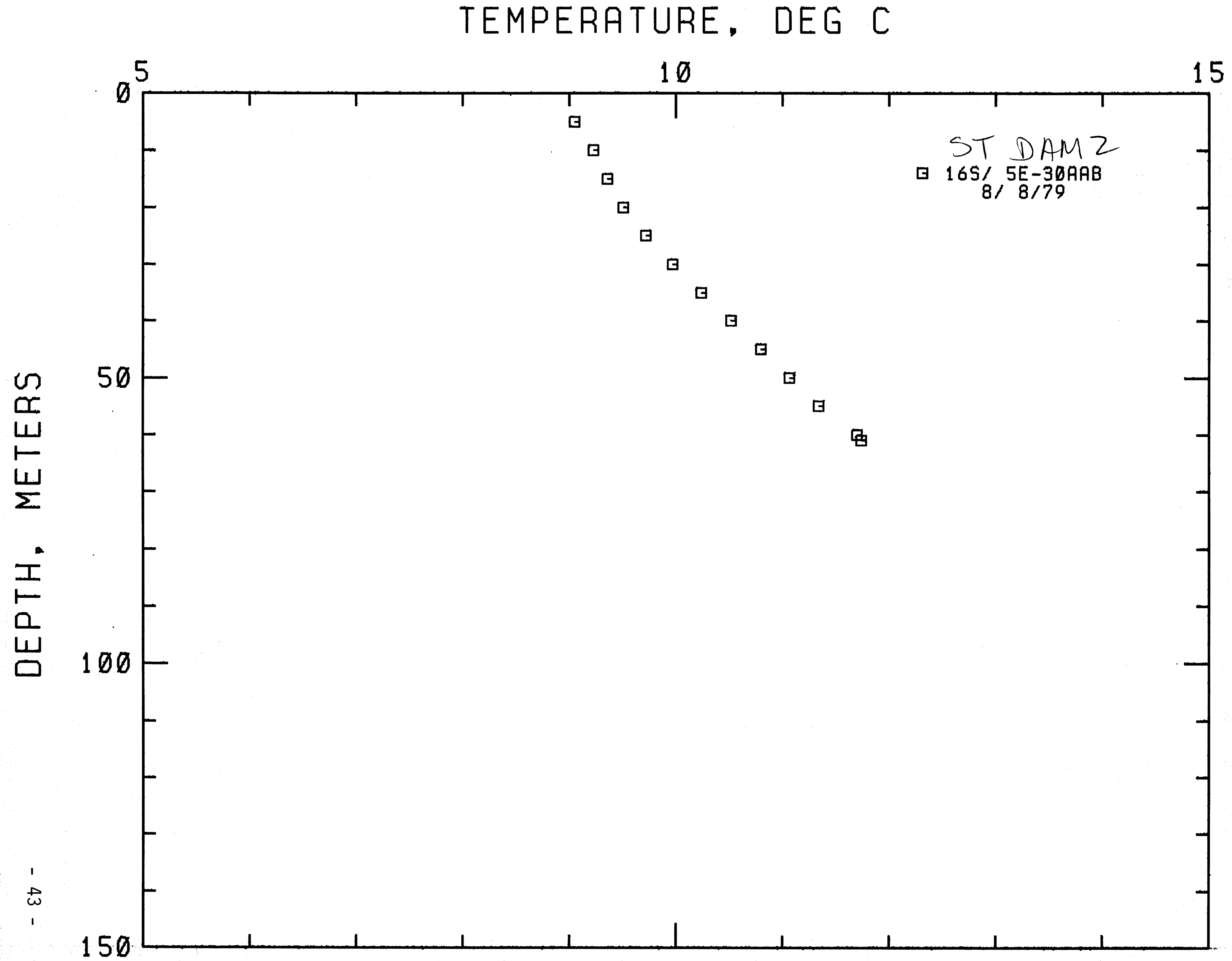
LOCATION: SALEM AMS, OREGON
16S/ 4E-14DBB
HOLE NUMBER: BH-32
DATE MEASURED: 11/26/75

DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	TEMPERATURE DEG F	GEOTHERMAL GRADIENT DEG C/KM	GEOTHERMAL GRADIENT DEG F/100 FT
5.0	16.4	9.460	49.03	0.0	0.0
7.5	24.6	9.120	48.42	-136.0	-7.5
10.0	32.8	9.310	48.76	76.0	4.2
12.5	41.0	9.470	49.05	64.0	3.5
15.0	49.2	9.560	49.21	36.0	2.0
17.5	57.4	9.640	49.35	32.0	1.8
20.0	65.6	9.720	49.50	32.0	1.8
22.5	73.8	9.820	49.68	40.0	2.2
25.0	82.0	9.920	49.86	40.0	2.2
27.5	90.2	10.010	50.02	36.0	2.0
30.0	98.4	10.100	50.18	36.0	2.0
32.5	106.6	10.180	50.32	32.0	1.8
35.0	114.8	10.280	50.50	40.0	2.2
37.5	123.0	10.390	50.70	44.0	2.4
40.0	131.2	10.490	50.88	40.0	2.2
42.5	139.4	10.610	51.10	48.0	2.6
45.0	147.6	10.700	51.26	36.0	2.0
47.5	155.8	10.760	51.37	24.0	1.3


TEMPERATURE, DEG C
5.0
11.0
DEPTH, METERS
.0
100.0
SALEM AMS. OREGON
+ 16S/4E/14DBB
11/26/76

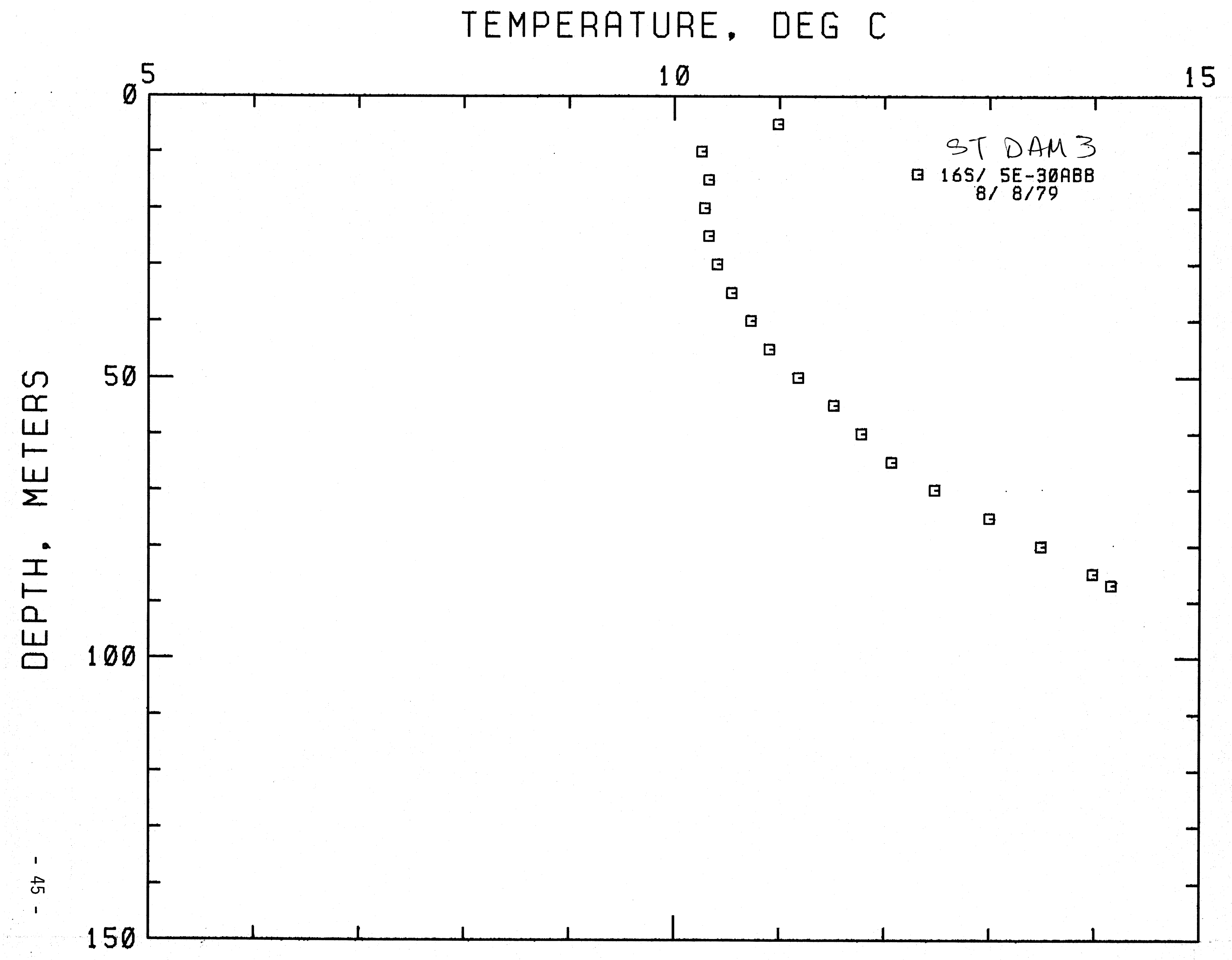
LOCATION: SALEM AMS, OREGON
16S/ 5E-30AAB
HOLE NAME: ST DAM 2
DATE MEASURED: 8/ 8/79

DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	TEMPERATURE DEG F	GEOTHERMAL GRADIENT DEG C/KM	GEOTHERMAL GRADIENT DEG F/100 FT
5.0	16.4	9.050	48.29	0.0	0.0
10.0	32.8	9.230	48.61	36.0	2.0
15.0	49.2	9.360	48.85	26.0	1.4
20.0	65.6	9.510	49.12	30.0	1.6
25.0	82.0	9.720	49.50	42.0	2.3
30.0	98.4	9.970	49.95	50.0	2.7
35.0	114.8	10.240	50.43	54.0	3.0
40.0	131.2	10.520	50.94	56.0	3.1
45.0	147.6	10.800	51.44	56.0	3.1
50.0	164.0	11.070	51.93	54.0	3.0
55.0	180.4	11.340	52.41	54.0	3.0
60.0	196.8	11.700	53.06	72.0	4.0
61.0	200.1	11.740	53.13	40.0	2.2


TEMPERATURE, DEG C
5
10
15
0
50
100
150
DEPTH, METERS
ST DAM 2
16S/ 5E-30AAB
8/ 8/79

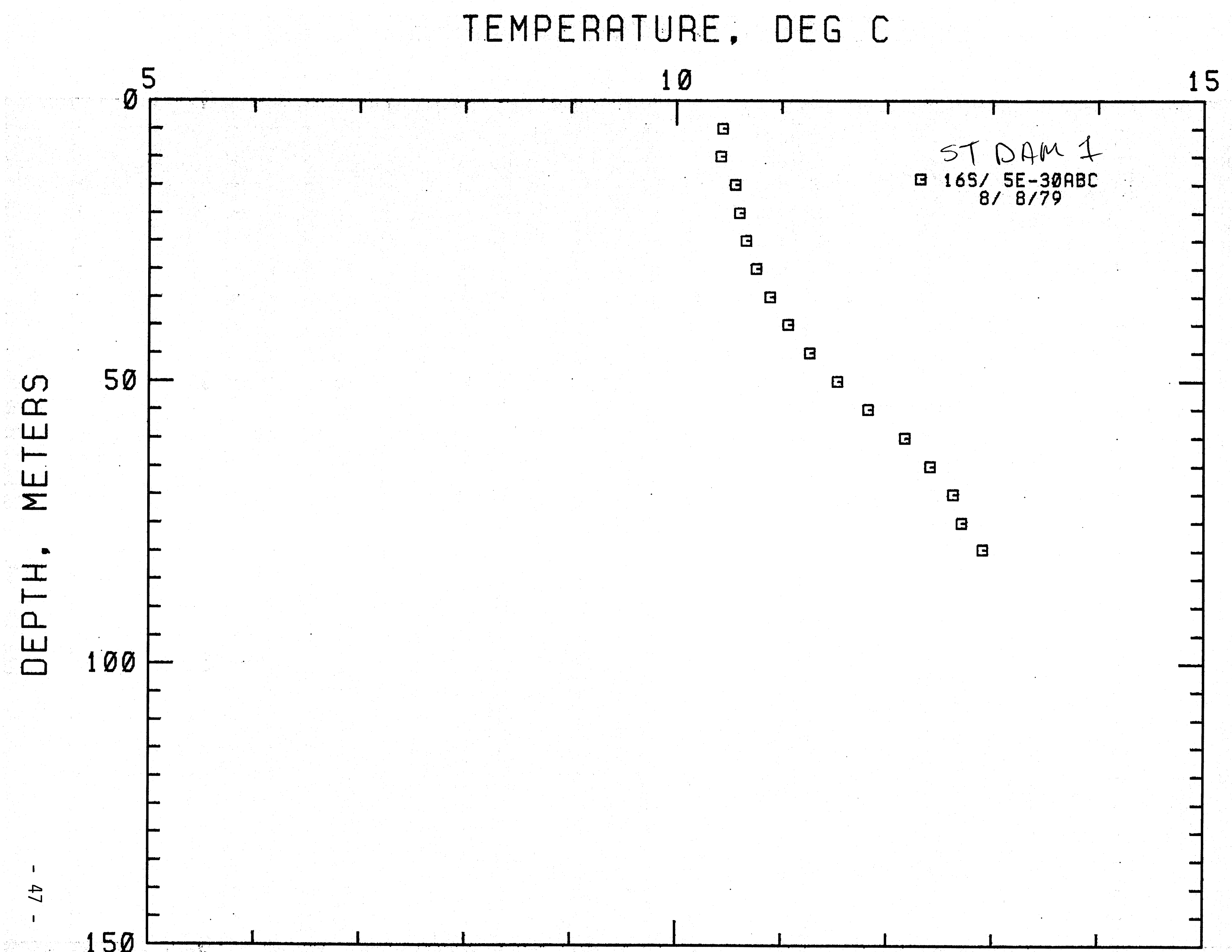
LOCATION: SALEM AMS, OREGON
16S/ 5E-30ABB
HOLE NAME: ST DAM 3
DATE MEASURED: 8/ 8/79

DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	TEMPERATURE DEG F	GEOTHERMAL GRADIENT DEG C/KM	GEOTHERMAL GRADIENT DEG F/100 FT
5.0	16.4	10.990	51.78	0.0	0.0
10.0	32.8	10.260	50.47	-146.0	-8.0
15.0	49.2	10.330	50.59	14.0	0.8
20.0	65.6	10.290	50.52	-8.0	-0.4
25.0	82.0	10.330	50.59	8.0	0.4
30.0	98.4	10.410	50.74	16.0	0.9
35.0	114.8	10.550	50.99	28.0	1.5
40.0	131.2	10.730	51.31	36.0	2.0
45.0	147.6	10.910	51.64	36.0	2.0
50.0	164.0	11.180	52.12	54.0	3.0
55.0	180.4	11.520	52.74	68.0	3.7
60.0	196.8	11.780	53.20	52.0	2.9
65.0	213.2	12.070	53.73	58.0	3.2
70.0	229.6	12.480	54.46	82.0	4.5
75.0	246.0	13.000	55.40	104.0	5.7
80.0	262.4	13.490	56.28	98.0	5.4
85.0	278.8	13.980	57.16	98.0	5.4
87.0	285.4	14.160	57.49	90.0	4.9


TEMPERATURE, DEG C
5
10
15
0
50
100
150
DEPTH, METERS
ST DAM 3
16S/ 5E-30ABB
8/ 8/79

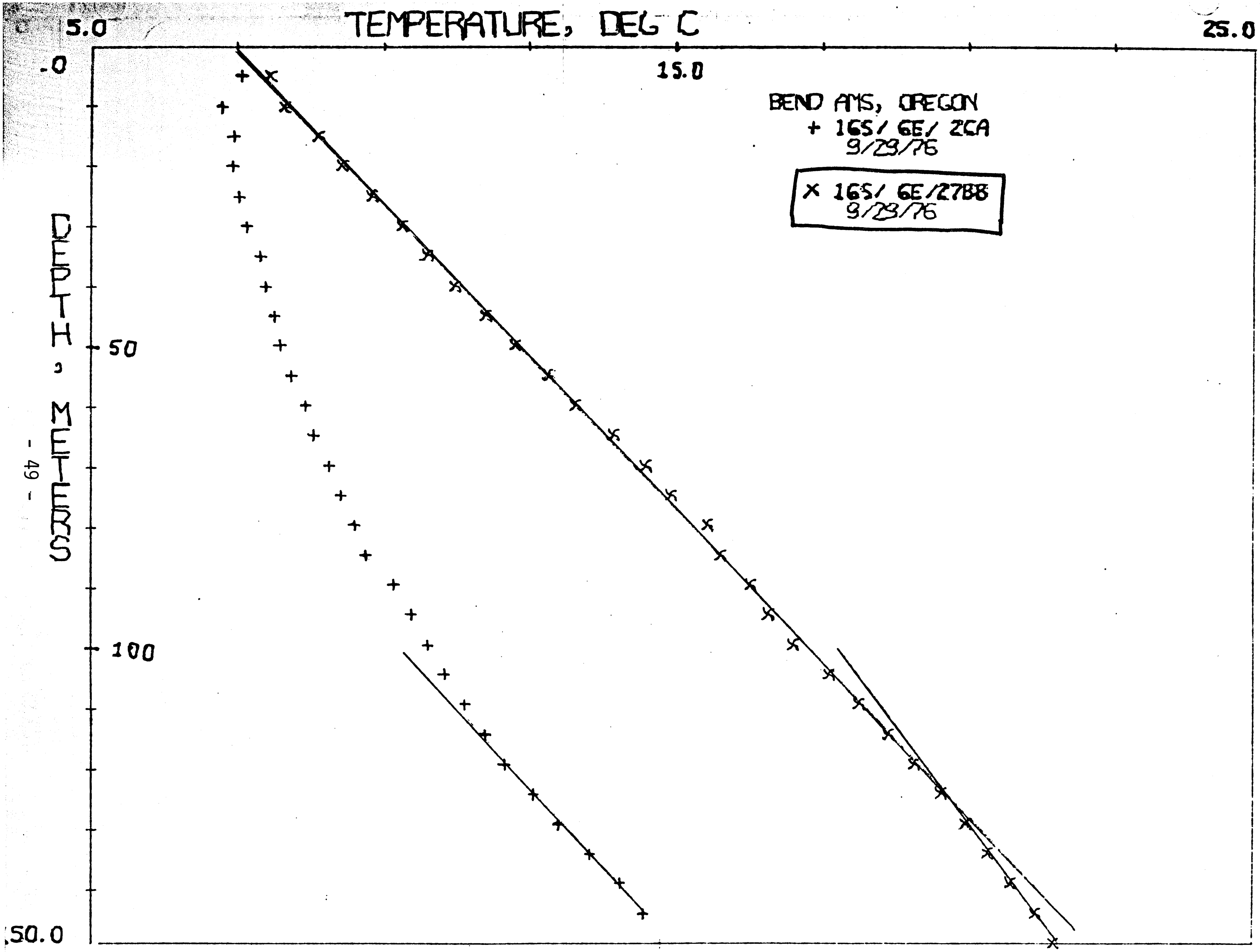
LOCATION: SALEM AMS, OREGON
16S/ 5E-30ABC
HOLE NAME: ST DAM 1
DATE MEASURED: 8/ 8/79

DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	TEMPERATURE DEG F	GEOTHERMAL GRADIENT DEG C/KM	GEOTHERMAL GRADIENT DEG F/100 FT
5.0	16.4	10.440	50.79	0.0	0.0
10.0	32.8	10.420	50.76	-4.0	-0.2
15.0	49.2	10.560	51.01	28.0	1.5
20.0	65.6	10.600	51.08	8.0	0.4
25.0	82.0	10.660	51.19	12.0	0.7
30.0	98.4	10.760	51.37	20.0	1.1
35.0	114.8	10.890	51.60	26.0	1.4
40.0	131.2	11.060	51.91	34.0	1.9
45.0	147.6	11.270	52.29	42.0	2.3
50.0	164.0	11.530	52.75	52.0	2.9
55.0	180.4	11.820	53.28	58.0	3.2
60.0	196.8	12.170	53.91	70.0	3.8
65.0	213.2	12.410	54.34	48.0	2.6
70.0	229.6	12.630	54.73	44.0	2.4
75.0	246.0	12.710	54.88	16.0	0.9
79.7	261.6	12.910	55.24	42.1	2.3


TEMPERATURE, DEG C
5
10
15
0
50
100
150
DEPTH, METERS
ST DAM 1
16S/ 5E-30ABC
8/ 8/79

LOCATION: SALEM AMS, OREGON
16S/ 6E/27BB
HOLE NUMBER: CR-HC
DATE MEASURED: 9/29/76

DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	TEMPERATURE DEG F	GEOTHERMAL GRADIENT DEG C/KM	GEOTHERMAL GRADIENT DEG F/100 FT
5.0	16.4	8.120	46.62	.0	.0
10.0	32.8	8.360	47.05	48.0	2.6
15.0	49.2	8.930	48.07	114.0	6.3
20.0	65.6	9.340	48.81	82.0	4.5
25.0	82.0	9.850	49.73	102.0	5.6
30.0	98.4	10.360	50.65	102.0	5.6
35.0	114.8	10.810	51.46	90.0	4.9
40.0	131.2	11.270	52.29	92.0	5.0
45.0	147.6	11.810	53.26	108.0	5.9
50.0	164.0	12.310	54.16	100.0	5.5
55.0	180.4	12.910	55.24	120.0	6.6
60.0	196.8	13.350	56.03	88.0	4.8
65.0	213.2	14.010	57.22	132.0	7.2
70.0	229.6	14.550	58.19	108.0	5.9
75.0	246.0	14.980	58.96	86.0	4.7
80.0	262.4	15.610	60.10	126.0	6.9
85.0	278.8	15.830	60.49	44.0	2.4
90.0	295.2	16.330	61.39	100.0	5.5
95.0	311.6	16.640	61.95	62.0	3.4
100.0	328.0	17.070	62.73	86.0	4.7
105.0	344.4	17.700	63.86	126.0	6.9
110.0	360.8	18.200	64.76	100.0	5.5
115.0	377.2	18.720	65.70	104.0	5.7
120.0	393.6	19.160	66.49	88.0	4.8
125.0	410.0	19.630	67.33	94.0	5.2
130.0	426.4	20.050	68.09	84.0	4.6
135.0	442.8	20.420	68.76	74.0	4.1
140.0	459.2	20.830	69.49	82.0	4.5
145.0	475.6	21.240	70.23	82.0	4.5
150.0	492.0	21.560	70.81	64.0	3.5



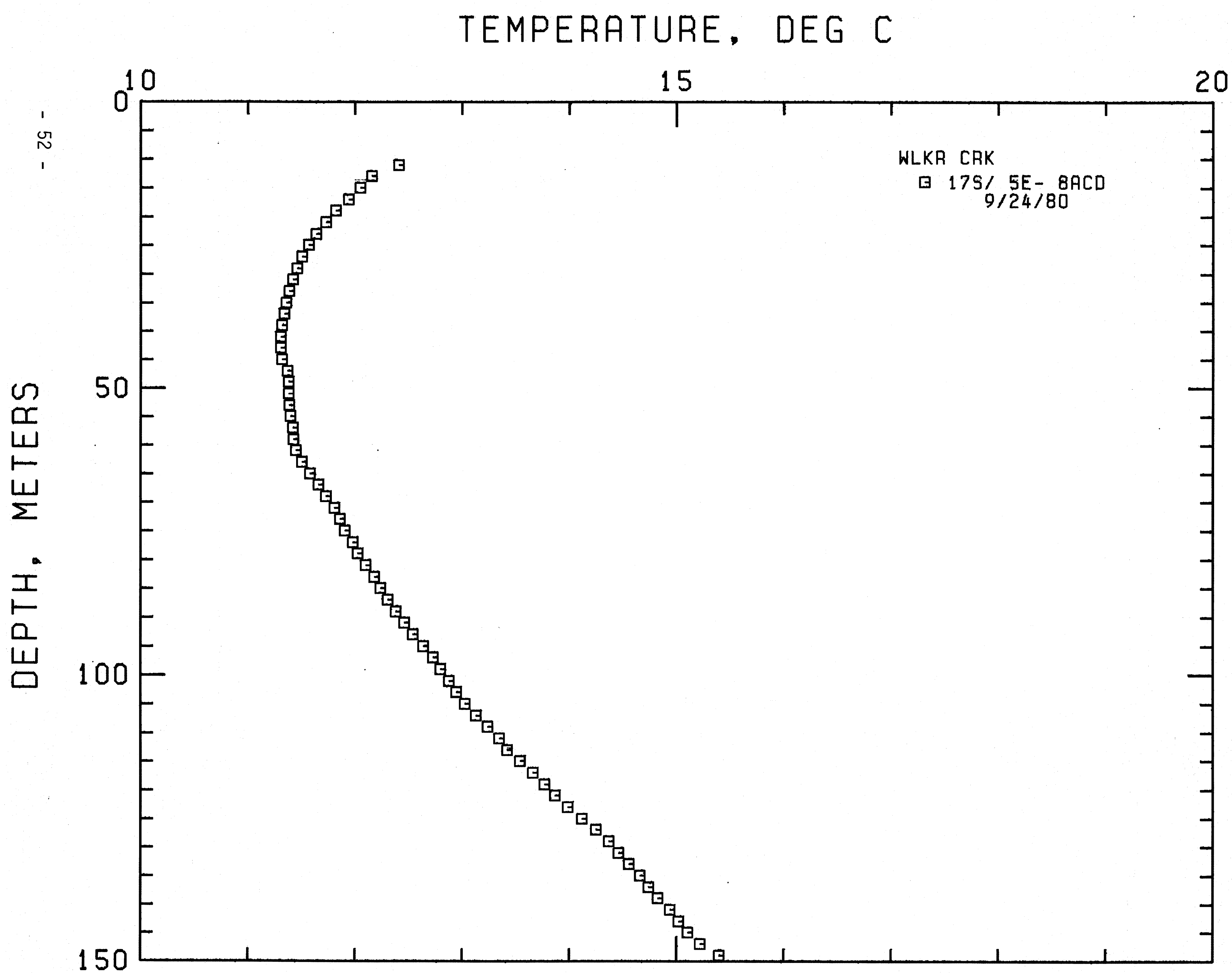
TEMPERATURE, DEG C
5.0
15.0
25.0
.0
50
100
150.0
DEPTH, METERS
BEND AMS, OREGON
+ 16S/ 6E/ 2CA
9/23/76
× 16S/ 6E/27BB
9/23/76

LOCATION: SALEM AMS, OREGON
17S/ 5E- 8ACD
HOLE NAME: WLKR CRK
DATE MEASURED: 9/24/80

DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	DEG F	GEOTHERMAL GRADIENT DEG C/KM	DEG F/100 FT
11.0	36.1	12.410	54.34	0.0	0.0
13.0	42.6	12.160	53.89	-125.0	-6.9
15.0	49.2	12.050	53.69	-55.0	-3.0
17.0	55.8	11.940	53.49	-55.0	-3.0
19.0	62.3	11.820	53.28	-60.0	-3.3
21.0	68.9	11.730	53.11	-45.0	-2.5
23.0	75.4	11.640	52.95	-45.0	-2.5
25.0	82.0	11.570	52.83	-35.0	-1.9
27.0	88.6	11.510	52.72	-30.0	-1.6
29.0	95.1	11.460	52.63	-25.0	-1.4
31.0	101.7	11.420	52.56	-20.0	-1.1
33.0	108.2	11.390	52.50	-15.0	-0.8
35.0	114.8	11.360	52.45	-15.0	-0.8
37.0	121.4	11.340	52.41	-10.0	-0.5
39.0	127.9	11.320	52.38	-10.0	-0.5
41.0	134.5	11.310	52.36	-5.0	-0.3
43.0	141.0	11.310	52.36	0.0	0.0
45.0	147.6	11.320	52.38	5.0	0.3
47.0	154.2	11.370	52.47	25.0	1.4
49.0	160.7	11.380	52.48	5.0	0.3
51.0	167.3	11.380	52.48	0.0	0.0
53.0	173.8	11.390	52.50	5.0	0.3
55.0	180.4	11.400	52.52	5.0	0.3
57.0	187.0	11.420	52.56	10.0	0.5
59.0	193.5	11.430	52.57	5.0	0.3
61.0	200.1	11.450	52.61	10.0	0.5
63.0	206.6	11.510	52.72	30.0	1.6
65.0	213.2	11.580	52.84	35.0	1.9
67.0	219.8	11.660	52.99	40.0	2.2
69.0	226.3	11.730	53.11	35.0	1.9
71.0	232.9	11.810	53.26	40.0	2.2
73.0	239.4	11.860	53.35	25.0	1.4
75.0	246.0	11.910	53.44	25.0	1.4
77.0	252.6	11.980	53.56	35.0	1.9
79.0	259.1	12.030	53.65	25.0	1.4
81.0	265.7	12.100	53.78	35.0	1.9
83.0	272.2	12.180	53.92	40.0	2.2
85.0	278.8	12.240	54.03	30.0	1.6
87.0	285.4	12.310	54.16	35.0	1.9
89.0	291.9	12.380	54.28	35.0	1.9
91.0	298.5	12.460	54.43	40.0	2.2

LOCATION: SALEM AMS, OREGON
17S/ 5E- 8ACD
HOLE NAME: WLKR CRK
DATE MEASURED: 9/24/80

DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	TEMPERATURE DEG F	GEOTHERMAL GRADIENT DEG C/KM	GEOTHERMAL GRADIENT DEG F/100 FT
93.0	305.0	12.540	54.57	40.0	2.2
95.0	311.6	12.640	54.75	50.0	2.7
97.0	318.2	12.730	54.91	45.0	2.5
99.0	324.7	12.800	55.04	35.0	1.9
101.0	331.3	12.880	55.18	40.0	2.2
103.0	337.8	12.950	55.31	35.0	1.9
105.0	344.4	13.030	55.45	40.0	2.2
107.0	351.0	13.130	55.63	50.0	2.7
109.0	357.5	13.240	55.83	55.0	3.0
111.0	364.1	13.350	56.03	55.0	3.0
113.0	370.6	13.420	56.16	35.0	1.9
115.0	377.2	13.540	56.37	60.0	3.3
117.0	383.8	13.660	56.59	60.0	3.3
119.0	390.3	13.770	56.79	55.0	3.0
121.0	396.9	13.870	56.97	50.0	2.7
123.0	403.4	13.990	57.18	60.0	3.3
125.0	410.0	14.120	57.42	65.0	3.6
127.0	416.6	14.250	57.65	65.0	3.6
129.0	423.1	14.370	57.87	60.0	3.3
131.0	429.7	14.460	58.03	45.0	2.5
133.0	436.2	14.560	58.21	50.0	2.7
135.0	442.8	14.660	58.39	50.0	2.7
137.0	449.4	14.740	58.53	40.0	2.2
139.0	455.9	14.830	58.69	45.0	2.5
141.0	462.5	14.940	58.89	55.0	3.0
143.0	469.0	15.020	59.04	40.0	2.2
145.0	475.6	15.110	59.20	45.0	2.5
147.0	482.2	15.220	59.40	55.0	3.0
149.0	488.7	15.400	59.72	90.0	4.9
151.0	495.3	15.530	59.95	65.0	3.6
153.0	501.8	15.640	60.15	55.0	3.0

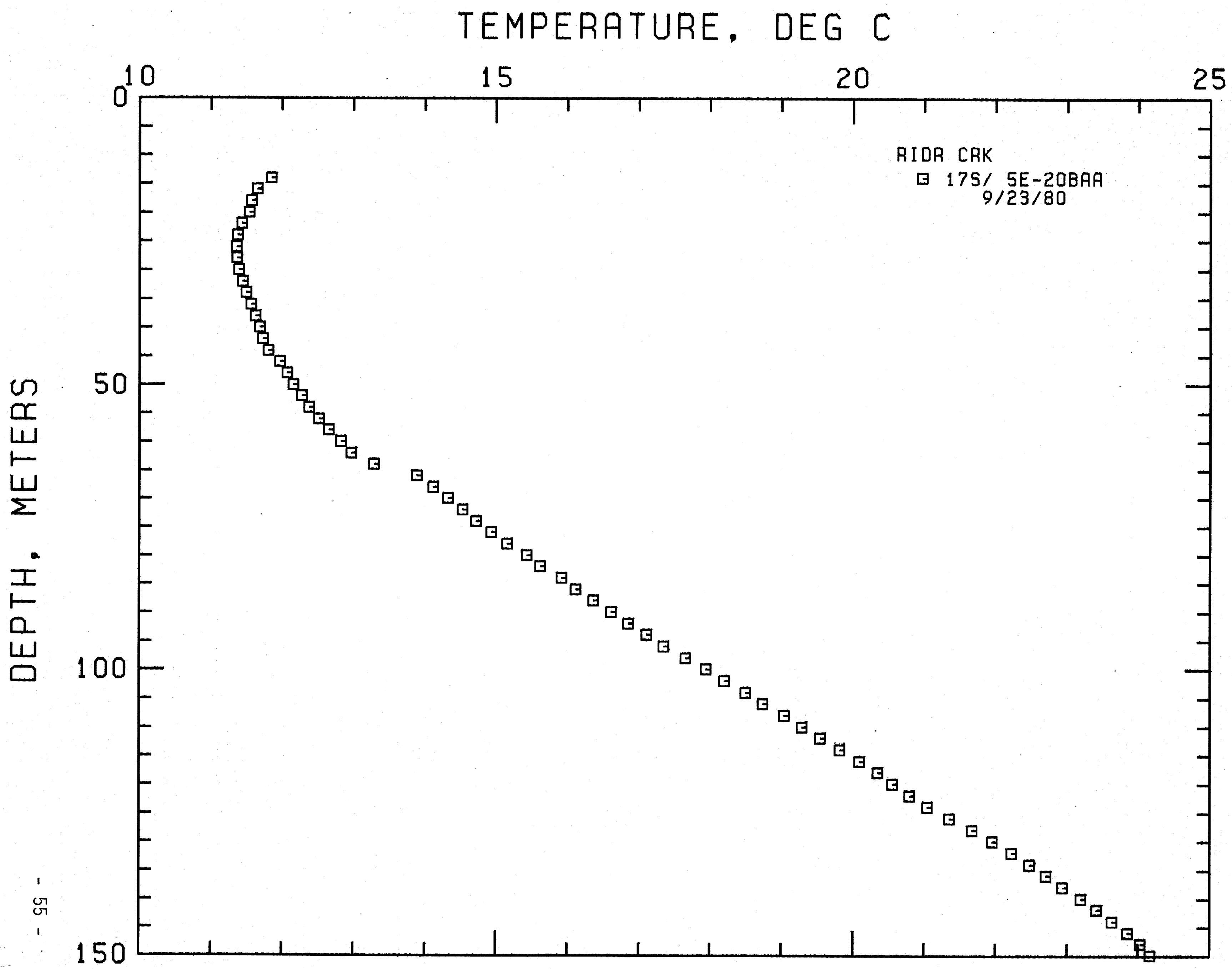

TEMPERATURE, DEG C
10
15
20
0
50
100
150
DEPTH, METERS
WLKR CRK
17S/ 5E- 8ACD
9/24/80

LOCATION: SALEM AMS, OREGON
17S/ 5E-20BAA
HOLE NAME: RIDR CRK
DATE MEASURED: 9/23/80

DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	TEMPERATURE DEG F	GEOTHERMAL GRADIENT DEG C/KM	GEOTHERMAL GRADIENT DEG F/100 FT
14.0	45.9	11.850	53.33	0.0	0.0
16.0	52.5	11.650	52.97	-100.0	-5.5
18.0	59.0	11.580	52.84	-35.0	-1.9
20.0	65.6	11.540	52.77	-20.0	-1.1
22.0	72.2	11.440	52.59	-50.0	-2.7
24.0	78.7	11.380	52.48	-30.0	-1.6
26.0	85.3	11.360	52.45	-10.0	-0.5
28.0	91.8	11.370	52.47	5.0	0.3
30.0	98.4	11.400	52.52	15.0	0.8
32.0	105.0	11.450	52.61	25.0	1.4
34.0	111.5	11.500	52.70	25.0	1.4
36.0	118.1	11.570	52.83	35.0	1.9
38.0	124.6	11.630	52.93	30.0	1.6
40.0	131.2	11.690	53.04	30.0	1.6
42.0	137.8	11.730	53.11	20.0	1.1
44.0	144.3	11.810	53.26	40.0	2.2
46.0	150.9	11.970	53.55	80.0	4.4
48.0	157.4	12.070	53.73	50.0	2.7
50.0	164.0	12.160	53.89	45.0	2.5
52.0	170.6	12.280	54.10	60.0	3.3
54.0	177.1	12.380	54.28	50.0	2.7
56.0	183.7	12.520	54.54	70.0	3.8
58.0	190.2	12.660	54.79	70.0	3.8
60.0	196.8	12.830	55.09	85.0	4.7
62.0	203.4	12.970	55.35	70.0	3.8
64.0	209.9	13.290	55.92	160.0	8.8
66.0	216.5	13.890	57.00	300.0	16.5
68.0	223.0	14.120	57.42	115.0	6.3
70.0	229.6	14.330	57.79	105.0	5.8
72.0	236.2	14.530	58.15	100.0	5.5
74.0	242.7	14.720	58.50	95.0	5.2
76.0	249.3	14.940	58.89	110.0	6.0
78.0	255.8	15.160	59.29	110.0	6.0
80.0	262.4	15.430	59.77	135.0	7.4
82.0	269.0	15.620	60.12	95.0	5.2
84.0	275.5	15.920	60.66	150.0	8.2
86.0	282.1	16.120	61.02	100.0	5.5
88.0	288.6	16.370	61.47	125.0	6.9
90.0	295.2	16.620	61.92	125.0	6.9
92.0	301.8	16.860	62.35	120.0	6.6
94.0	308.3	17.110	62.80	125.0	6.9

LOCATION: SALEM AMS, OREGON
17S/ 5E-20BAA
HOLE NAME: RIDR CRK
DATE MEASURED: 9/23/80

DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	TEMPERATURE DEG F	GEOTHERMAL GRADIENT DEG C/KM	GEOTHERMAL GRADIENT DEG F/100 FT
96.0	314.9	17.350	63.23	120.0	6.6
98.0	321.4	17.660	63.79	155.0	8.5
100.0	328.0	17.950	64.31	145.0	8.0
102.0	334.6	18.200	64.76	125.0	6.9
104.0	341.1	18.500	65.30	150.0	8.2
106.0	347.7	18.740	65.73	120.0	6.6
108.0	354.2	19.040	66.27	150.0	8.2
110.0	360.8	19.290	66.72	125.0	6.9
112.0	367.4	19.550	67.19	130.0	7.1
114.0	373.9	19.820	67.68	135.0	7.4
116.0	380.5	20.100	68.18	140.0	7.7
118.0	387.0	20.350	68.63	125.0	6.9
120.0	393.6	20.560	69.01	105.0	5.8
122.0	400.2	20.800	69.44	120.0	6.6
124.0	406.7	21.050	69.89	125.0	6.9
126.0	413.3	21.360	70.45	155.0	8.5
128.0	419.8	21.670	71.01	155.0	8.5
130.0	426.4	21.960	71.53	145.0	8.0
132.0	433.0	22.230	72.01	135.0	7.4
134.0	439.5	22.480	72.46	125.0	6.9
136.0	446.1	22.710	72.88	115.0	6.3
138.0	452.6	22.940	73.29	115.0	6.3
140.0	459.2	23.200	73.76	130.0	7.1
142.0	465.8	23.420	74.16	110.0	6.0
144.0	472.3	23.640	74.55	110.0	6.0
146.0	478.9	23.850	74.93	105.0	5.8
148.0	485.4	24.030	75.25	90.0	4.9
150.0	492.0	24.170	75.51	70.0	3.8
152.0	498.6	24.480	76.06	155.0	8.5

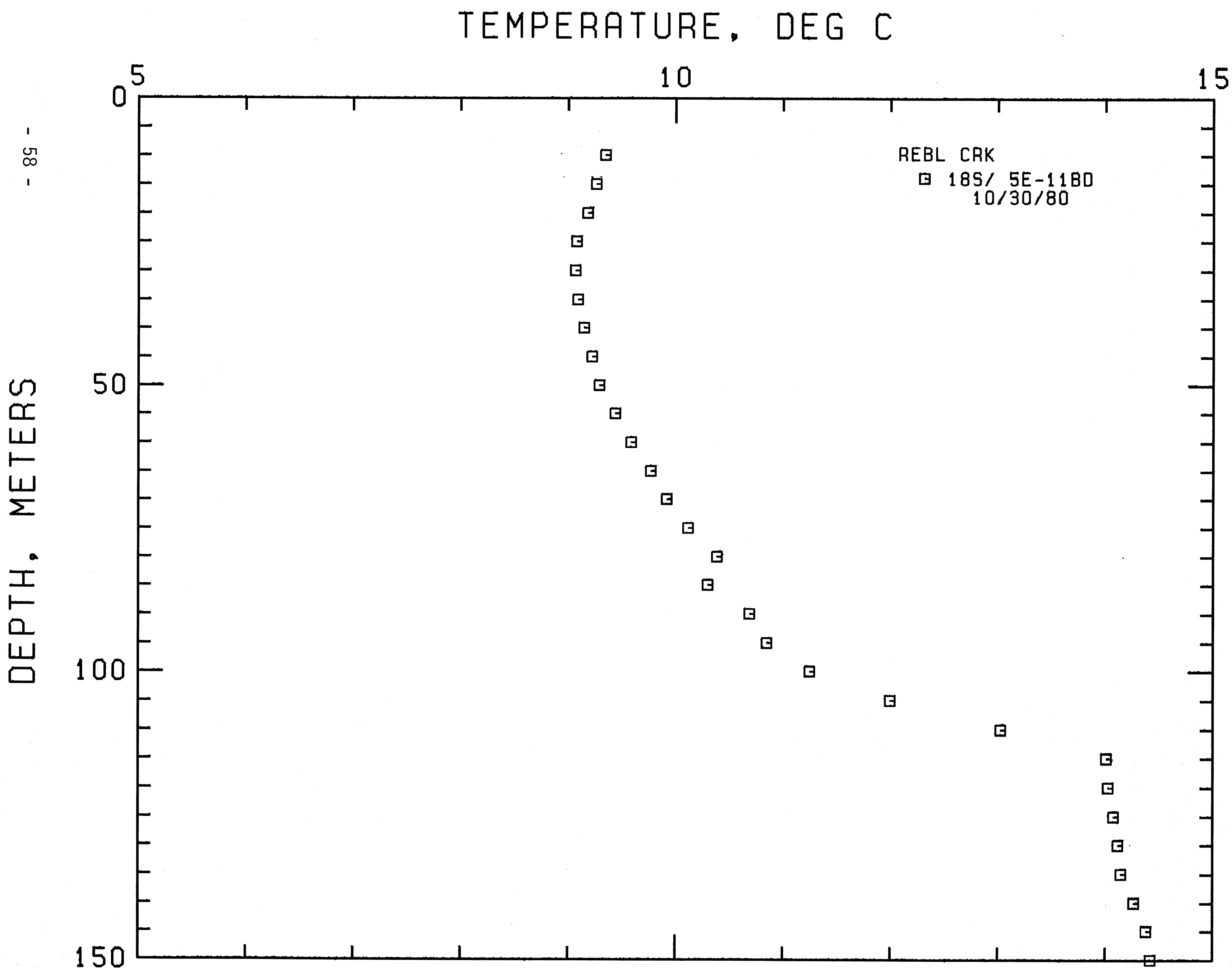

TEMPERATURE, DEG C
10
15
20
25
0
50
100
150
DEPTH, METERS
RIDA CRK
17S/ 5E-20BAA
9/23/80

LOCATION: SALEM AMS, OREGON
17S/ 6E-25AD
HOLE NAME: MOSQ CRK
DATE MEASURED: 9/24/80

DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	TEMPERATURE DEG F	GEOTHERMAL GRADIENT DEG C/KM	GEOTHERMAL GRADIENT DEG F/100 FT
15.0	49.2	6.940	44.49	0.0	0.0
17.0	55.8	6.920	44.46	-10.0	-0.5
19.0	62.3	6.920	44.46	0.0	0.0
21.0	68.9	6.910	44.44	-5.0	-0.3
23.0	75.4	6.920	44.46	5.0	0.3
25.0	82.0	6.940	44.49	10.0	0.5
27.0	88.6	6.950	44.51	5.0	0.3
29.0	95.1	6.980	44.56	15.0	0.8
31.0	101.7	7.010	44.62	15.0	0.8
33.0	108.2	7.040	44.67	15.0	0.8
35.0	114.8	7.070	44.73	15.0	0.8
37.0	121.4	7.100	44.78	15.0	0.8
39.0	127.9	7.130	44.83	15.0	0.8
41.0	134.5	7.160	44.89	15.0	0.8
43.0	141.0	7.190	44.94	15.0	0.8
45.0	147.6	7.220	45.00	15.0	0.8
47.0	154.2	7.260	45.07	20.0	1.1
49.0	160.7	7.300	45.14	20.0	1.1
51.0	167.3	7.330	45.19	15.0	0.8
53.0	173.8	7.360	45.25	15.0	0.8
55.0	180.4	7.390	45.30	15.0	0.8
57.0	187.0	7.430	45.37	20.0	1.1
59.0	193.5	7.460	45.43	15.0	0.8
61.0	200.1	7.490	45.48	15.0	0.8
63.0	206.6	7.520	45.54	15.0	0.8
65.0	213.2	7.550	45.59	15.0	0.8
67.0	219.8	7.580	45.64	15.0	0.8
69.0	226.3	7.610	45.70	15.0	0.8
71.0	232.9	7.640	45.75	15.0	0.8
73.0	239.4	7.670	45.81	15.0	0.8
75.0	246.0	7.700	45.86	15.0	0.8
77.0	252.6	7.730	45.91	15.0	0.8
79.0	259.1	7.760	45.97	15.0	0.8
81.0	265.7	7.790	46.02	15.0	0.8
83.0	272.2	7.820	46.08	15.0	0.8
85.0	278.8	7.850	46.13	15.0	0.8
87.0	285.4	7.890	46.20	20.0	1.1
89.0	291.9	7.930	46.27	20.0	1.1
91.0	298.5	7.970	46.35	20.0	1.1
93.0	305.0	8.010	46.42	20.0	1.1
95.0	311.6	8.060	46.51	25.0	1.4

LOCATION: SALEM AMS, OREGON
18S/ 5E-11BD
HOLE NAME: REBL CRK
DATE MEASURED: 10/30/80

DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	TEMPERATURE DEG F	GEOTHERMAL GRADIENT DEG C/KM	GEOTHERMAL GRADIENT DEG F/100 FT
10.0	32.8	9.350	48.83	0.0	0.0
15.0	49.2	9.260	48.67	-18.0	-1.0
20.0	65.6	9.180	48.52	-16.0	-0.9
25.0	82.0	9.080	48.34	-20.0	-1.1
30.0	98.4	9.070	48.33	-2.0	-0.1
35.0	114.8	9.090	48.36	4.0	0.2
40.0	131.2	9.150	48.47	12.0	0.7
45.0	147.6	9.220	48.60	14.0	0.8
50.0	164.0	9.290	48.72	14.0	0.8
55.0	180.4	9.440	48.99	30.0	1.6
60.0	196.8	9.590	49.26	30.0	1.6
65.0	213.2	9.770	49.59	36.0	2.0
70.0	229.6	9.920	49.86	30.0	1.6
75.0	246.0	10.120	50.22	40.0	2.2
80.0	262.4	10.390	50.70	54.0	3.0
85.0	278.8	10.300	50.54	-18.0	-1.0
90.0	295.2	10.690	51.24	78.0	4.3
95.0	311.6	10.850	51.53	32.0	1.8
100.0	328.0	11.250	52.25	80.0	4.4
105.0	344.4	12.000	53.60	150.0	8.2
110.0	360.8	13.030	55.45	206.0	11.3
115.0	377.2	14.010	57.22	196.0	10.8
120.0	393.6	14.030	57.25	4.0	0.2
125.0	410.0	14.080	57.34	10.0	0.5
130.0	426.4	14.120	57.42	8.0	0.4
135.0	442.8	14.150	57.47	6.0	0.3
140.0	459.2	14.270	57.69	24.0	1.3
145.0	475.6	14.380	57.88	22.0	1.2
150.0	492.0	14.420	57.96	8.0	0.4


TEMPERATURE, DEG C
5
10
15
0
50
100
150
DEPTH, METERS
REBL CRK
18S/ 5E-11BD
10/30/80