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AIRPORT GRAVITY BASE STATION NETWORK IN OREGON

By

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Introduction

The force of gravity or gravitational attraction is familiar to all, but not everyone knows that the value of gravity at any point on the earth's surface is a variable that depends upon latitude, elevation, tidal effects, topography, and the density distribution of the rocks beneath the surface.

Gravity surveying is commonly used today in the search for oil and gas or metallic minerals, but long before gravity measurements became prospecting tools it was realized that such measurements could give information on the shape of the earth and the nature, thickness, and mechanical properties of its crust.

The accelerating pace of geophysical measurements has resulted in the need for more base stations of standard gravity values to which this constantly increasing volume of new information can be related. The Geophysical Research Group, Department of Oceanography, Oregon State University, and the Oregon Department of Geology and Mineral Industries, seeing the need for base stations in Oregon for both their own work and that of others coming into the area, have cooperated in establishing a series of 23 gravity base stations at secondary airports in central and southern Oregon (see figure 1). This survey was carried out by using a light four-place airplane (Cessna 172). A Worden Master Gravity Meter, No. 575, was flown between the gravity stations. By this method a wide area was covered in a minimum of time and with a minimum expenditure of funds. The work was done in the spring of 1963 and took a total of 40 flying hours.

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Measurement of Gravity

Gravity measurements are obtained by either of two methods: pendulum or gravity meter. The pendulum method requires specially constructed pendulums and highly accurate crystal clocks. The pendulum oscillations are timed for a period of several hours and a direct determination of the acceleration of gravity can be calculated. The accuracy obtained depends upon the timing and the freedom from losses due to friction in the pendulum. This is the method by which all gravity measurements were formerly taken, but it has now been largely supplanted by the gravity meter.

Gravity meters are relative-reading devices which indicate the change in acceleration of gravity between known stations. This change is measured by determining the relative position of a spring-supported weight through the use of highly sensitive optical magnifiers. The accuracy of a gravity value obtained with a gravity meter depends on the accuracy of the primary base station, the knowledge of the meter's calibration constant, and the precision of measurement. The precision of the meter and its operator may be determined by statistically analyzing the variations in readings made between one station and another. The gravity meter tends to have a varying amount of drift that is dependent upon such factors as time, temperature, and vibration. Ideally, temperature and vibration of the meter can be controlled and the time drift is a straight line factor. The data collected by gravity meters must be referred to a known base value of gravity in order to be used in regional and geodetic gravity surveys, and the more often this data can be tied in to a base station the more accurate it will be.

Earlier Gravity Stations in Oregon

In the State of Oregon, gravity values were first obtained in 1910 by the U.S. Coast and Geodetic Survey, using a pendulum device (Duerksen, 1949). These readings were obtained at coastal stations and in the Willamette Valley. A control network at airports in the United States was completed in 1958 (Woollard, 1958), using gravity meters. This network contains 9 Oregon stations located at Portland (2), Salem, Corvallis, Eugene, North Bend, Medford, Roseburg, and Pendleton. These gravity stations were tied to the primary West Coast base stations located at Seattle, Washington, and San Francisco, California. In turn, these base stations, which are part of the North American Western Standardization Range, were tied by Woollard to the gravity base station located at the University of Wisconsin. The gravity value there is based on ties made by Woollard (1950) to 11 international gravity base stations tied directly to Potsdam, Germany.

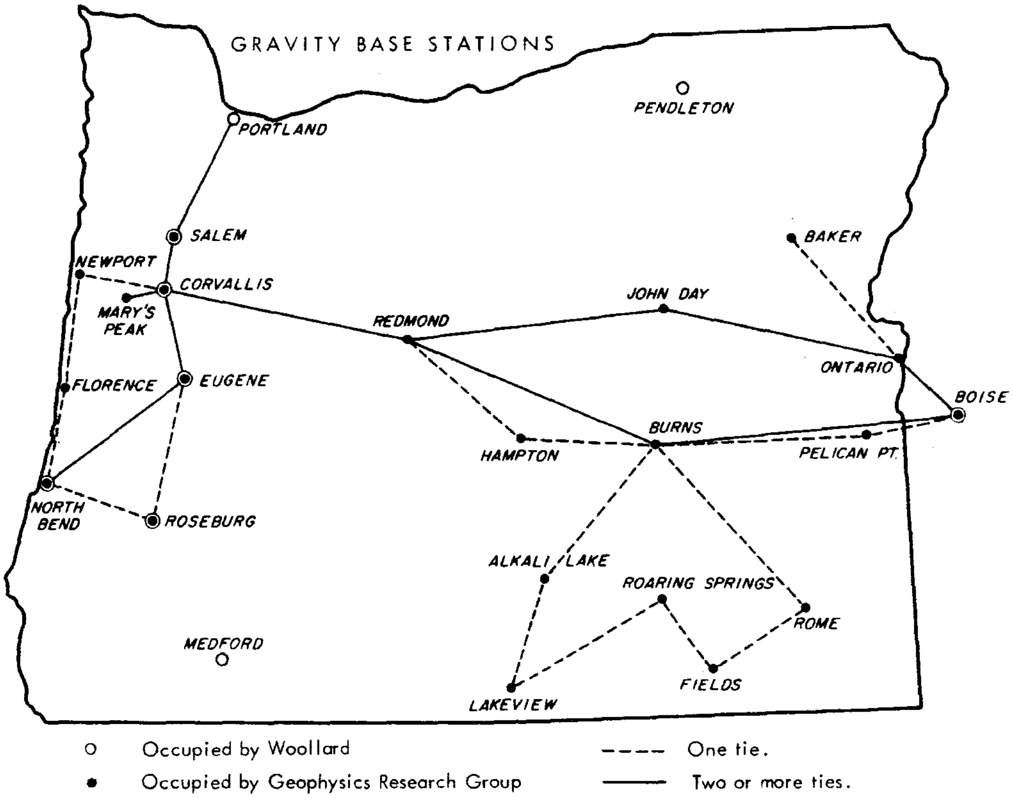

Figure 1. Index map showing location of gravity base stations in Oregon.

Base Stations Added in 1963

The locations of the 23 airport stations are shown as solid circles in figure 1. The solid connecting lines indicate multiple ties between stations and constitute a first order gravity base network. The dashed connecting lines indicate one tie between stations and constitute a second order gravity base network, because the precision of measurement, and consequently its accuracy, could not be evaluated.

Figure 2 (see pages 53, 54, 55, and 56) shows a plan view of each site, which should permit reoccupation of the stations to within 5 feet. Where it was possible, sites were chosen near permanent structures, but in some instances sites were located at the wind sock, a nearby bench mark, or at a road intersection.

Occupying sites described by Woollard (1963), primary ties were made between the Portland airport and the Salem, Corvallis, and Eugene airports. Secondary ties were then made between the Corvallis and Redmond airports.

Table I. Observed gravity values in Oregon.

1	2	3	4	5	6	7
Station (Airport)	Ties	OSU Observed Gravity (mgal)	Woollard Observed Gravity (mgal)	USCGS Observed Gravity (mgal)	Differences (col 4-col 3) (mgal)	(col 5-col 3) (mgal)
Portland (Primary Base Station)			980648.3			
Corvallis	4 a	980569.0	980570.1		-1.1	
Salem	4 a	980583.3	980583.7		-0.4	
Eugene	6 ab	980514.6	980514.8		-0.2	
North Bend	3 b	980492.2	980493.5		-1.3	
Redmond	2 b	980260.8				
John Day	2 c	980242.4				
Pelican Point	1 c	980208.5				
Ontario	2 c	980303.5				
Baker	1 c	980286.6				
Burns	2 c	980105.9				
Hampton	1 c	980095.1				
Rome	1 c	980039.7				
Fields	1 c	979972.9				
Roaring Springs	1 c	979985.6				
Lakeview	1 c	979901.5				
Alkali Lake	1 c	980046.6				
Roseburg	1 b	980427.7	980429.4		-1.7	
Newport	1 b	980596.2				
Florence	1 b	980550.0				
Boise, Idaho	2 b	980207.1	980208.2		-1.1	
Medford			980237.5			
Pendleton			980511.7			
OSU Physics-Chemistry Building	15 ab	980573.4				
Portland Custom House	5 a	980647.5	980647.4	980649.	+0.1	-1.5
Eugene Pendulum Station	1 b	980489.8	980490.2	980493.	-0.4	-3.2
Mary's Peak	2 b	980362.6				

a- Tied to Portland Airport
b- Tied to Corvallis Airport
c- Tied to Redmond Airport

All stations east of the Cascade Mountains were tied to the Redmond airport station, and the coastal and Willamette Valley stations were tied to the Corvallis airport station.

Column 2 of table 1 indicates the number of ties made to one of these three stations (Portland, Corvallis, or Redmond). Column 3 lists the observed gravity obtained by the Geophysics Research Group; column 4 lists the observed gravity reported by Woollard; and column 5 lists the observed gravity reported by the U.S. Coast and Geodetic Survey. The difference (column 4 minus column 3) between Woollard's value and the G.R.G. value is listed in column 6. The difference (column 5 - column 3) between the U.S.C. and G.S. value and the G.R.G. value is listed in column 7.

The difference between the G.R.G. and Woollard's observed value at the Corvallis airport is approximately the same as the differences between values at North Bend and Roseburg, Oregon, and Boise, Idaho. The North Bend, Roseburg, and Boise stations are tied directly or indirectly to the Corvallis airport station. Woollard's value at Medford, Oregon, is 1.1 mgals higher than the gravity value observed by Harrison and Corbato (1963).

Using the G.R.G. value obtained at the Corvallis airport, ties have been made to a geodetic gravity station established by Harrison and Corbato (1963) located on the Oregon State University campus. This tie resulted in a difference of 0.04 mgal. The Harrison and Corbato value for the O.S.U. campus station was based on the observed gravity at the Geology-Chemistry Building at the University of California, Los Angeles, which, in turn, was determined by ties to the North American Western and Pacific Coast Standardization Ranges (Woollard and Rose, 1963).

Conclusion

The relative accuracy of this survey depends upon the precision with which the measurements were made and can be statistically calculated. The standard errors of measurement of nine groups of observations ranged from 0.00 mgal to 0.11 mgal. The pooled estimate of the standard errors is 0.06 mgal. Over all, the G.R.G. gravity measurements at all bases established during this work are accurate to at least 0.1 mgal relative to the Portland airport value.

The absolute values used in this survey depend only upon the value accepted as representing true gravity at the Portland airport. The reliability of Woollard's nationwide airport network is reported as greater than 0.5 mgal (1958). An independent measurement at the Portland airport by Harrison and Corbato (1963) was within 0.2 mgal of Woollard's observed value.

Acknowledgments

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(Illustrations continued on pages 53 to 56.)

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STATE SUBMERGED LANDS OPENED TO LEASING

The State Land Board has set May 1, 1964, as the deadline for accepting nominations for state submerged lands to be considered for oil and gas leasing. Selections of state lands must be made by parcel numbers established by the land board and platted on an official lease map. The map may be inspected at the State Land Board office, 106 State Capitol Building, Salem, or copies can be purchased at a cost of $15 each, plus postage. Nominations for leasing of fractional parcels will not be accepted.

Nominations should be placed in a sealed envelope within a larger envelope so they can be held confidential until all selections can be considered simultaneously. Designation of parcels to be considered for leasing will be by number only and will be announced by mid-May. No fee is required for filing nominations.

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AMERICAN MINING CONGRESS CONVENTION

Portland, Oregon September 13 - 16, 1964

GRAVITY FIELD OVER ZONES OF MAJOR TECTONISM, SOUTHWEST OREGON

By

M. A. Kays and J. L. Bruemmer*

Introduction

A long-range program involving structural, petrographic, and gravimetric analysis was initiated during the summer of 1963 to better understand the tectonic framework and evolution of the pre-Tertiary Klamath Mountain complex of southwest Oregon. As indicated in figure 1, the most obvious structural features of this region are north-northeast trending faults. Work thus far has proceeded on the premise that basic to a better understanding of the tectonic framework is a detailed examination of these major structural features. The fact that many of the dense ultramafic bodies in the pre-Tertiary of this region have been emplaced in direct contact with less dense rocks along major faults makes gravity work a cogent tool in enhancing our knowledge of the structure. Large density differences between rock bodies in fault contact (Δ d = 0.2-0.4 gram/cc) are sufficient to contribute considerably to development of local gravity anomalies depending upon inclination, depth, and extent of the rock bodies. Thus gravity work allows more meaningful interpretations based upon detailed surface studies of structure and petrography.

General Geology and Rock Densities

The area of investigation, largely in the Galice quadrangle, is of particular interest for its location in the heart of the Klamath Mountain complex in southwestern Oregon and for the presence of five major faults (fig. 1). The general geology and age relations of the major units in the area have been summarized in modified form (fig. 2) from Wells and Walker (1953). Contact relations indicate rock bodies that approximate a series of slabs striking N. 10° to 30° E. and dipping on an average of 60°

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SE.; trends of the major faults are closely conformable to the strike of the major units. Coincident with each of the five major faults, Hansen Saddle, Cedar Mountain, Hungry Hill, East and West Hellgate, are narrow elongate lenses or pods of partially serpentinized peridotite and serpentinite. With exception of the Hansen Saddle-Cedar Mountain fault system, where contact relations are complicated by quartz diorite to the west and amphibolite gneiss to the east, the peridotite-serpentinite association is found in sharp contact with eugeosynclinal sedimentary and volcanic rocks (fig. 2).

Densities for the major rock types in the Galice quadrangle are reported in Table I from measurements of 49 rock samples. It should be emphasized that the rock densities are average values, and local values may be greater than given for the most dense assemblage (up to 3.2 gram/cc) and less than given for the least dense assemblage (as low as 2.4 gram/cc). The average density for the Galice and Dothan Formations combined is 2.67 gram/cc which is the value used in Bouguer reduction* procedures. Therefore, average density differences between peridotite, amphibolite, quartz diorite, and the adjacent eugeosynclinal sedimentary and volcanic rocks are taken to be 0.31, 0.27, and 0.16 respectively (fig. 3). The average density difference between recrystallized sedimentary and volcanic rocks along faults and the adjacent unrecrystallized sedimentary and volcanic rocks ranges from 0.27 to 0.31. In this case, no distinction can be made between peridotite and recrystallized rocks along the fault. The differences in density between major rock types, however, should certainly be reflected in the Bouguer gravity distribution where each rock type occurs in a body of appreciable extent. From the surface distribution of the rock bodies together with the superposed gravity pattern, it should be possible to deduce the inclination of these bodies and their extent in depth; in short, to interpret the geometry of the complex in three dimensions.

Gravity Observations

The gravity distribution (fig. 2) conforms remarkably well to the pattern of major lithologic units. In general, areas underlain by unrecrystallized sedimentary rocks (and some intrusive granitic rocks) are associated with broad, open gravity lows. The Dothan Formation in the northwestern and western parts of the Galice quadrangle and the Galice Formation in the eastern part of the quadrangle show this relationship. Belts of recrystallized sedimentary and volcanic rocks, partially serpentinized peridotite,

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* Bouguer reduction: a correction made in gravity work to take account of the altitude of the station and the rock between the station and sea level.

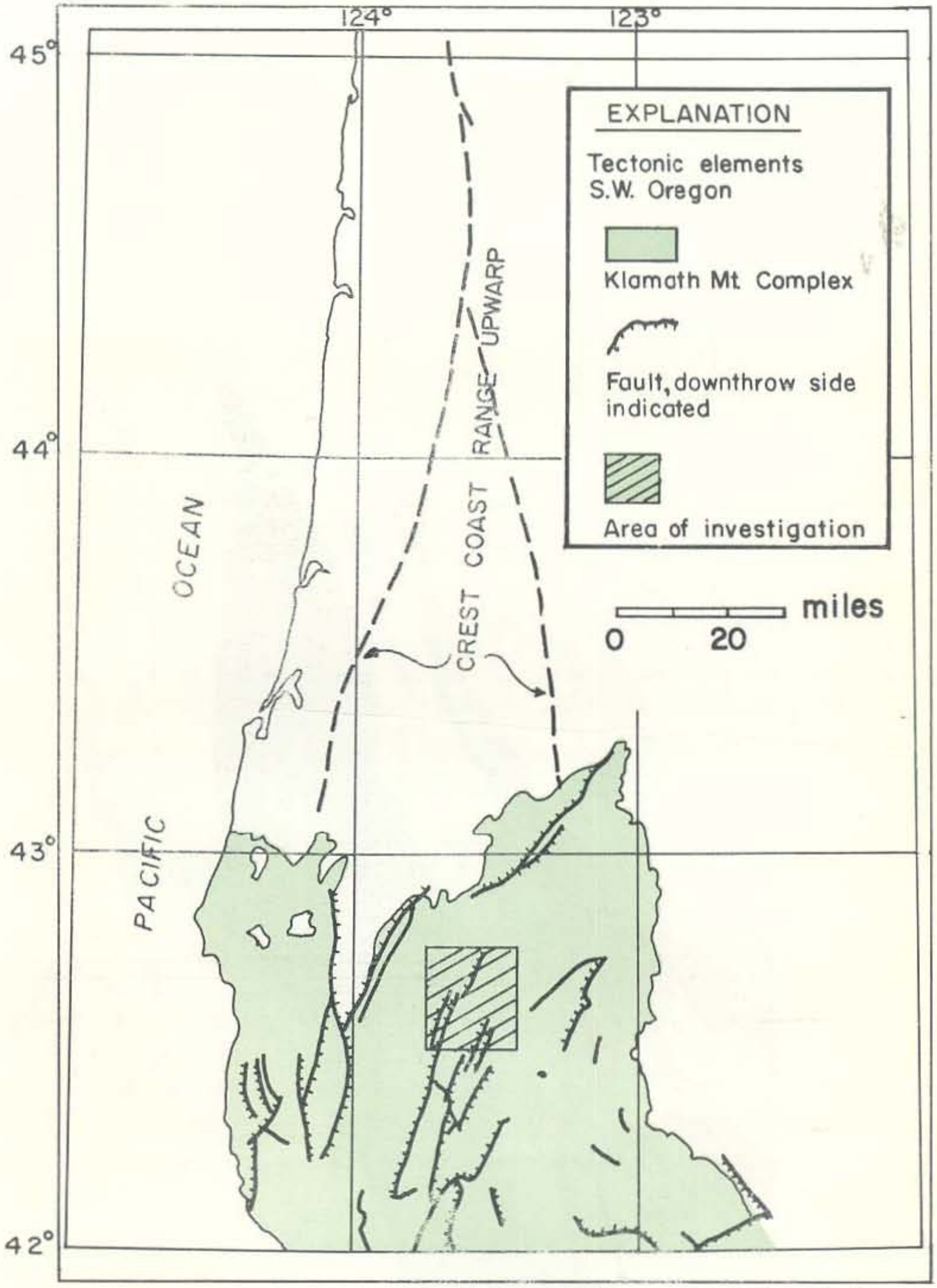


Figure 1. Tectonic map adapted from Wells and Peck (1961) showing location of area of investigation and major structural features in the pre-Tertiary of southwest Oregon.

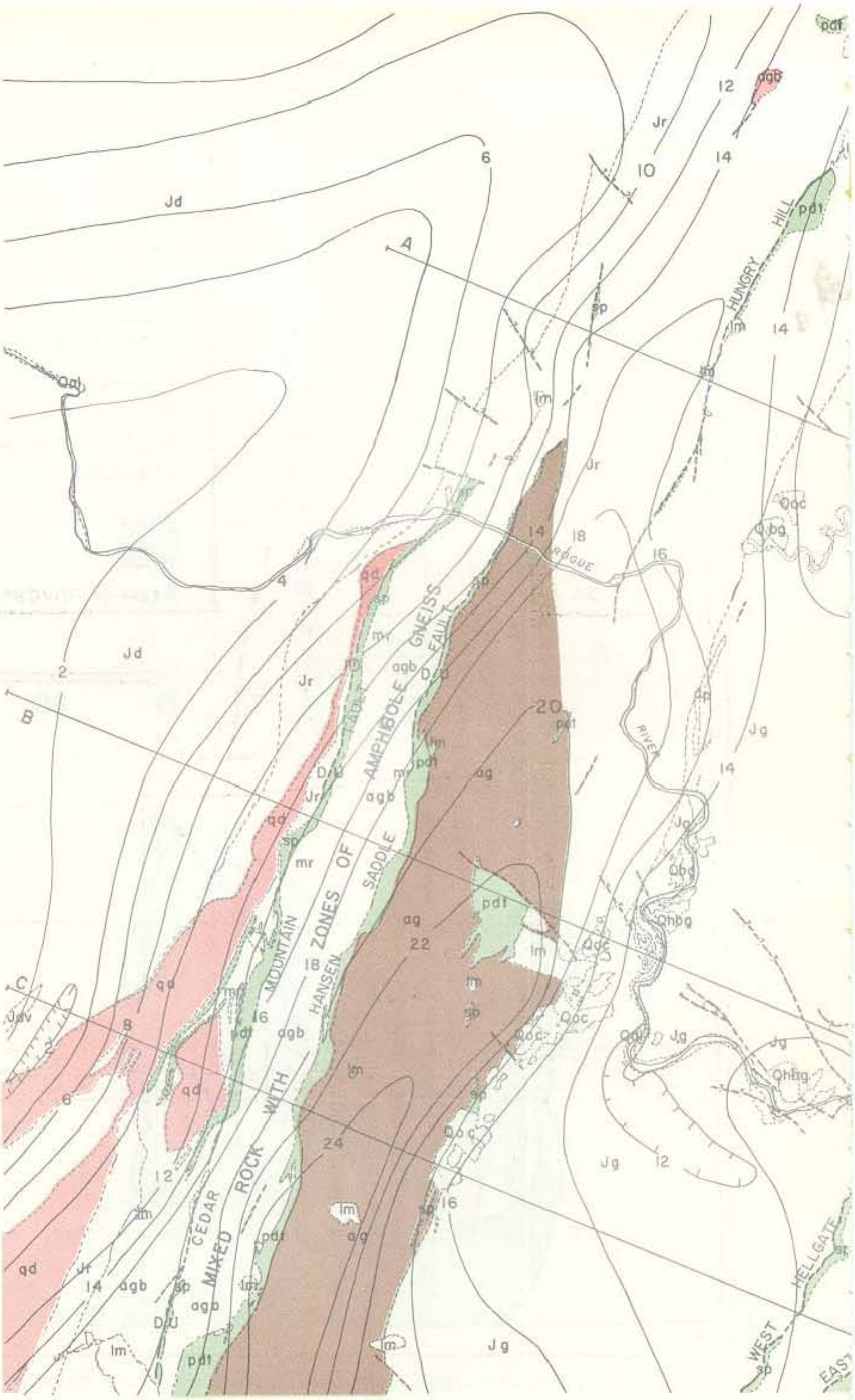
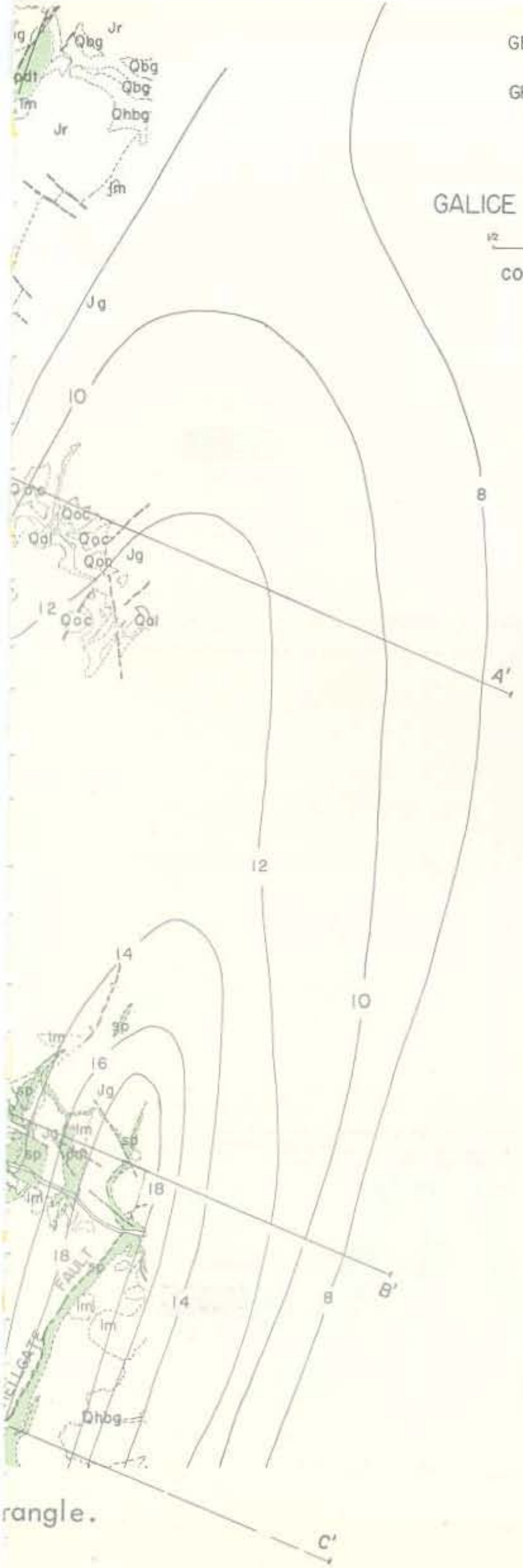


Figure 2. Combined geologic and Bouguer gravity map, Galice qu



rangle.

GEOLOGIC AND BOUGUER GRAVITY ANOMALY MAP OF THE GALICE QUADRANGLE, OREGON

1/2 0 1 2 MILES

CONTOUR INTERVAL 2 MILLIGALS

LEGEND

QUATERNARY

- Qal — Alluvium
- Qbg & Qhbg — Bench gravels
- Qoc — Channel gravels

JURASSIC OR CRETACEOUS

- dp — dacite porphyry
- qd — Quartz diorite
- agb — Amphibolite of gabbroic habit
- pdt sp — peridotite & serpentine
- mr — Mixed rocks

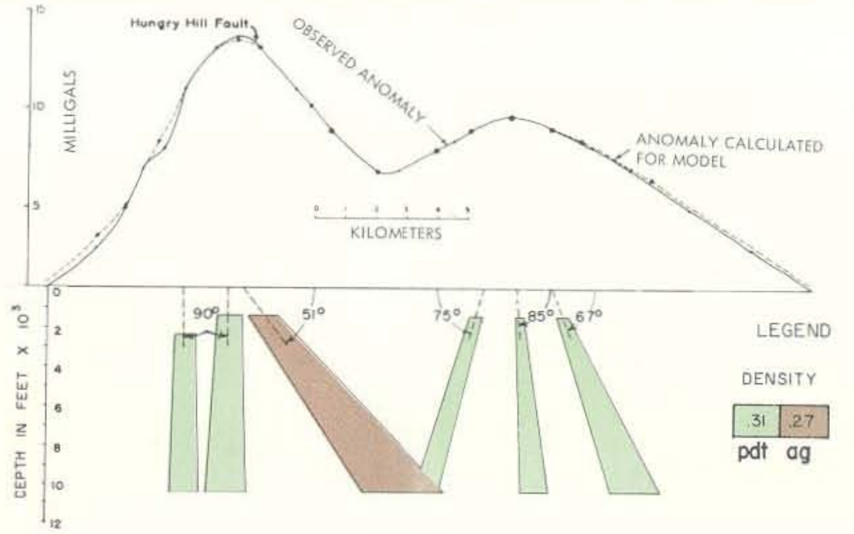
JURASSIC

- Jg — Galice fm.
- Jr — Rogue fm.; ag — Amphibole gneiss
- Jd — Dothan fm.

- lm — Landslide material

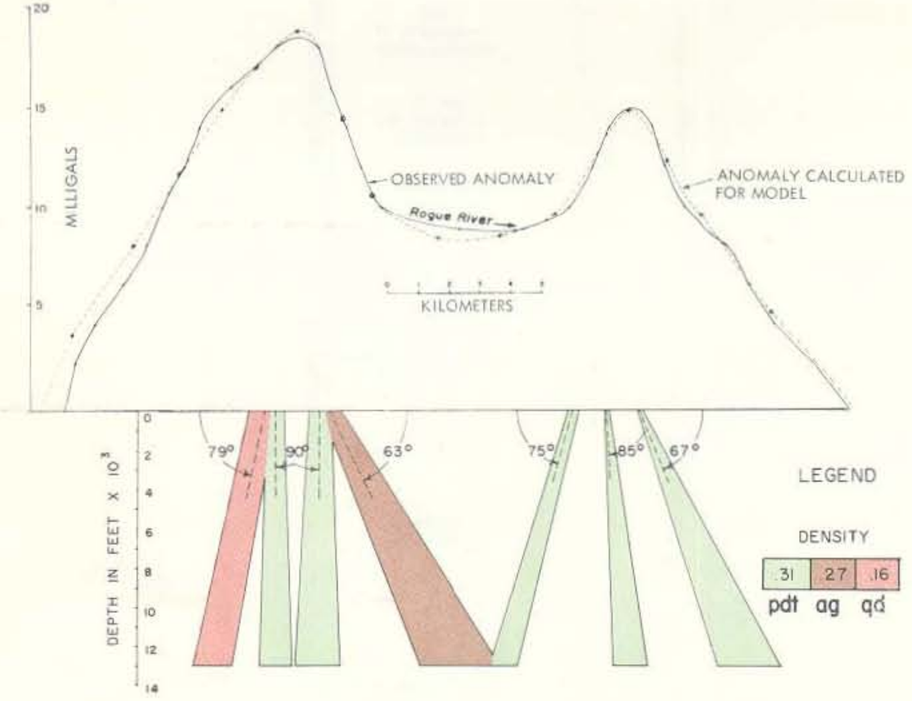
GENERALIZED FROM
WELLS & WALKER (1953)

GRAVITY DATA BY
M. A. KAYS &
J. L. BRUEMMER
IN 1963



GRAVITY PROFILE & MATHEMATICAL DENSITY MODEL

FOR PROFILE A-A'



GRAVITY PROFILE & MATHEMATICAL DENSITY MODEL

FOR PROFILE B-B'

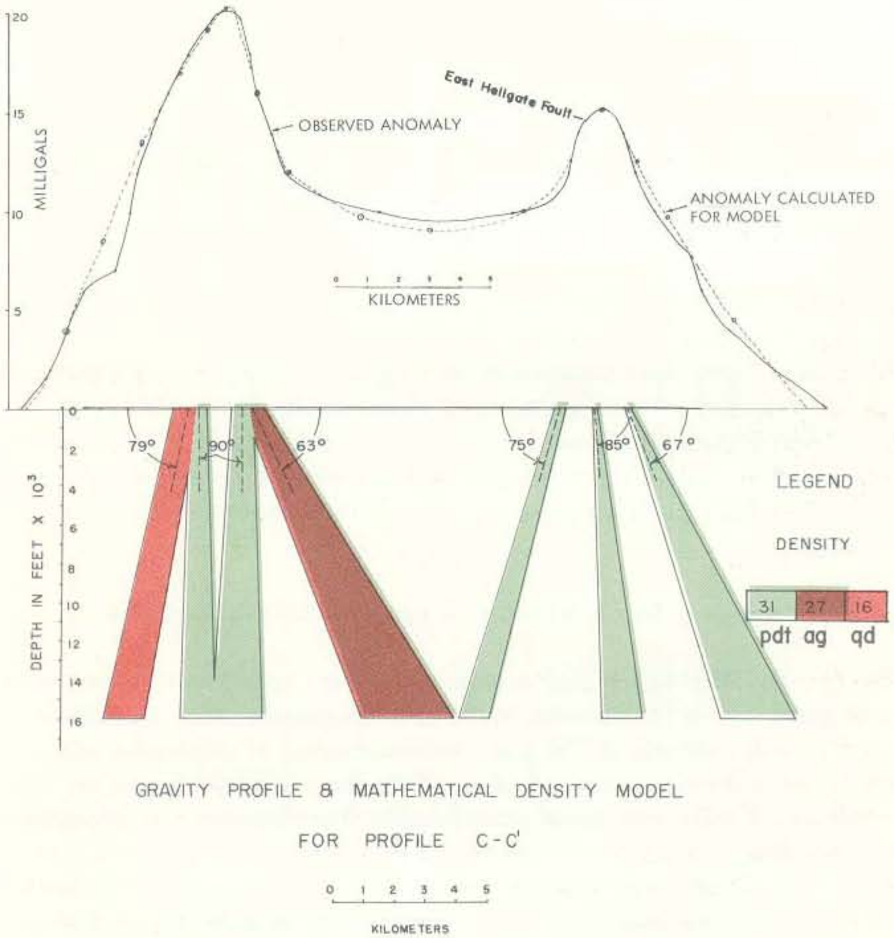


Figure 3. Observed and computed gravity profiles along AA', BB', CC', and relation to the mathematical density model. Four milligals have been subtracted from all Bouguer gravity observations in order that these profiles can be compared with the theoretical profiles.

and amphibolite gneiss, all adjacent to major faults, are associated with sharp, well-defined gravity highs. The major gravity high in the quadrangle trends northeast, paralleling the Hansen Saddle-Cedar Mountain fault zone in the south and the Hungry Hill fault in the north. This gravity high coincides specifically with the partially serpentinized peridotite-amphibolite gneiss association. The effect on the gravity distribution by adjacent less dense sedimentary rocks is noticeable in the steepness of the gravity gradient as these units are approached. A smaller but well-defined gravity high, with up to 5 mgals of closure (fig. 2) coincides with the less extensive Hellgate fault system and the attendant recrystallized Galice-serpentinized peridotite association.

All gravity data were reduced according to the Bouguer reduction procedures for a density of 2.67 gram/cc as described by Swick (1942, p. 60-68). Terrain corrections were made out to a distance of 20 kilometers from each station according to an approximate method described by Kane (1962, p. 455-462), utilizing computer facilities available at the University of Oregon.

Interpretations of the Gravity Distribution

The gravity distribution thus appears to reflect both location and magnitude of major tectonic elements in the Galice quadrangle. This observation holds only because of the peculiar occurrence of ultramafic and recrystallized rocks along major faults. From the regional viewpoint, moreover, this peculiarity may be of considerable significance, for injection of peridotite along major faults appears to be the rule rather than the exception. Thus, it may well be that gravity maps in this region essentially represent the tectonic framework. Further, several preliminary interpretations of the subsurface extent of units exposed, based upon surface geology and gravity observations, are possible at this time. However, these interpretations are viewed by the authors as only rough order of magnitude approximations which may serve as preliminary models to be tested in resolving the major structural features of southwestern Oregon.

The present interpretation of the subsurface configuration of the various rock bodies is based on the development of a geometric model which satisfies both surface geologic data and gravity distribution. Skeels (1963, personal communication) suggested that a method of successive estimations of the gravity distribution produced by a series of slabs would give the best fit, and in a recent paper (1963) gave an approximate solution for the problem of depth compensation. The model adopted here involves slabs of dense rock -- peridotite, amphibolite, or quartz diorite -- with various dips separated by bodies of lighter rocks. In order to obtain satisfactory correspondence between profiles computed from the model and observed profiles, it is necessary to allow thickening of the slabs with depth, and to use a different depth of compensation for each profile. As the latter restriction is concerned only with the magnitude of a gravity anomaly and not with its shape, it does not conflict with realistic geometric interpretation; in fact, the variation in compensation required here seems compatible with apparent lateral change in magnitude of the structural elements at the surface. Analysis of a number of postulated geometric models was carried out using Ramsey's (1940, p. 30) equation.

For profile AA' (fig. 3), a model involving slabs which extend from 1,500 to 10,500 feet produces a theoretical profile which agrees closely with the observed gravity. The Hansen Saddle-Cedar Mountain peridotite-amphibolite association and the Hellgate fault association each involve three mutually exclusive slabs of denser rock. Models with the same basic geometry also provide good fits with the observed profiles BB' and CC' (fig. 3) when depths of compensation of 13,000 and 16,000 feet respectively are adopted.

The important point is that one basic model of the subsurface geometry with only minor modifications produces close approximations of the observed gravity in three different profiles. Although gravity analysis indicated some minor modifications, this model also agrees in general with the geologic cross section of Wells and Walker (1953).

Table I. Densities of major rock types in the Galice quadrangle.

Density (gram/cc)	No. Samples	Occurrence or Rock Type
2.64	6	Dothan Formation - argillites and graywackes
2.75	2	Quartz diorite intrusives
3.01	4	Peridotite - serpentinite association
2.92	8	Hornblende gabbro and schistose rocks of the mixed rock zone
2.97	13	Amphibolite gneiss of the Rogue (?) Formation
2.90	5	Rogue Formation - partially recrystallized sedimentary and volcanic rocks
2.69	5	Galice Formation - sedimentary and volcanic rocks
2.85	6	Galice Formation - recrystallized sedimentary and volcanic rocks

Conclusions

On the basis of surface geology and gravity data, in certain cases, the amount of peridotite injected appears to be directly related to the magnitude and extent of faulting. Results of calculations based upon geometric models indicate that the faults dip steeply. Depths of compensation required indicate that they extend $2\frac{1}{2}$ to 3 miles downward into the crust. The peridotite masses broaden and appear to coalesce eventually.

Certain problems are encountered in regard to petrologic models to explain the occurrence of some of the lithologic units. The amphibolite gneiss, for example, appears distinctly out of place with respect to the rocks immediately adjacent which are essentially unmetamorphosed volcanic and sedimentary rocks. The localized distribution of these metamorphic rocks seems to preclude widespread regional metamorphism. However, faults roughly coincident with the bodies of amphibolite gneiss suggest that rocks of amphibolite facies grade may be prevalent at depth, and that the present outcrops represent tectonic blocks carried up along major faults during forceful injection of peridotite.

Acknowledgments

Data reduction which included terrain corrections to distances of 20 kilometers from each station was facilitated by the 1620 IBM digital computer at the University of Oregon. The authors are indebted to B.J. Witt for providing them with his generalized computer program. Thanks are also due Dr. G. T. Benson, who kindly read the manuscript, and Dr. V.E. McMath, who offered many helpful suggestions. This study was supported in part by a Faculty Summer Research Grant from the Office of Scientific and Scholarly Research of the University of Oregon.

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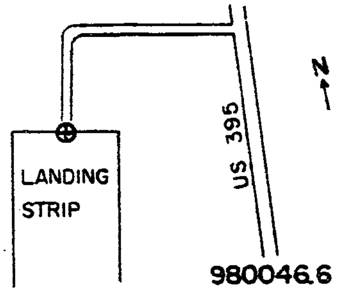
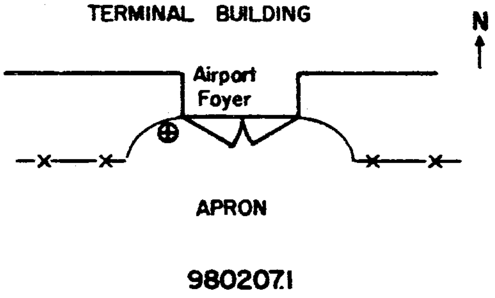
(Airport Gravity Base Station Network in Oregon, continued.)

ALKALI LAKE



BOISE MUNICIPAL AIRPORT



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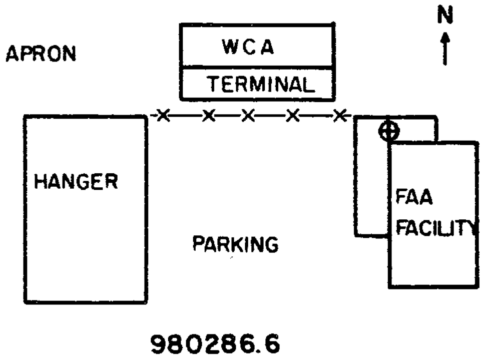

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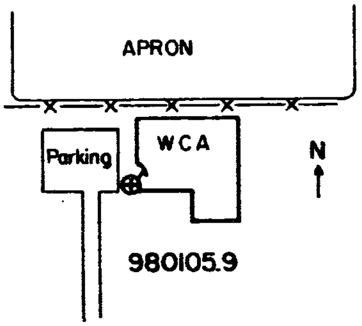
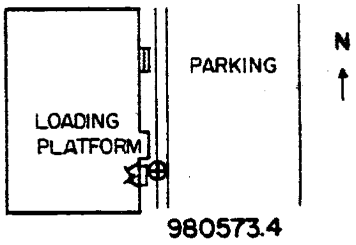


Corvallis Physics-Chemisty Bldg



CORVALLIS AIRPORT

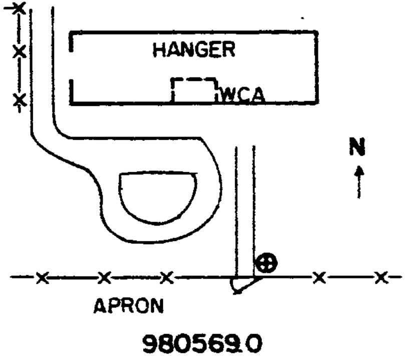
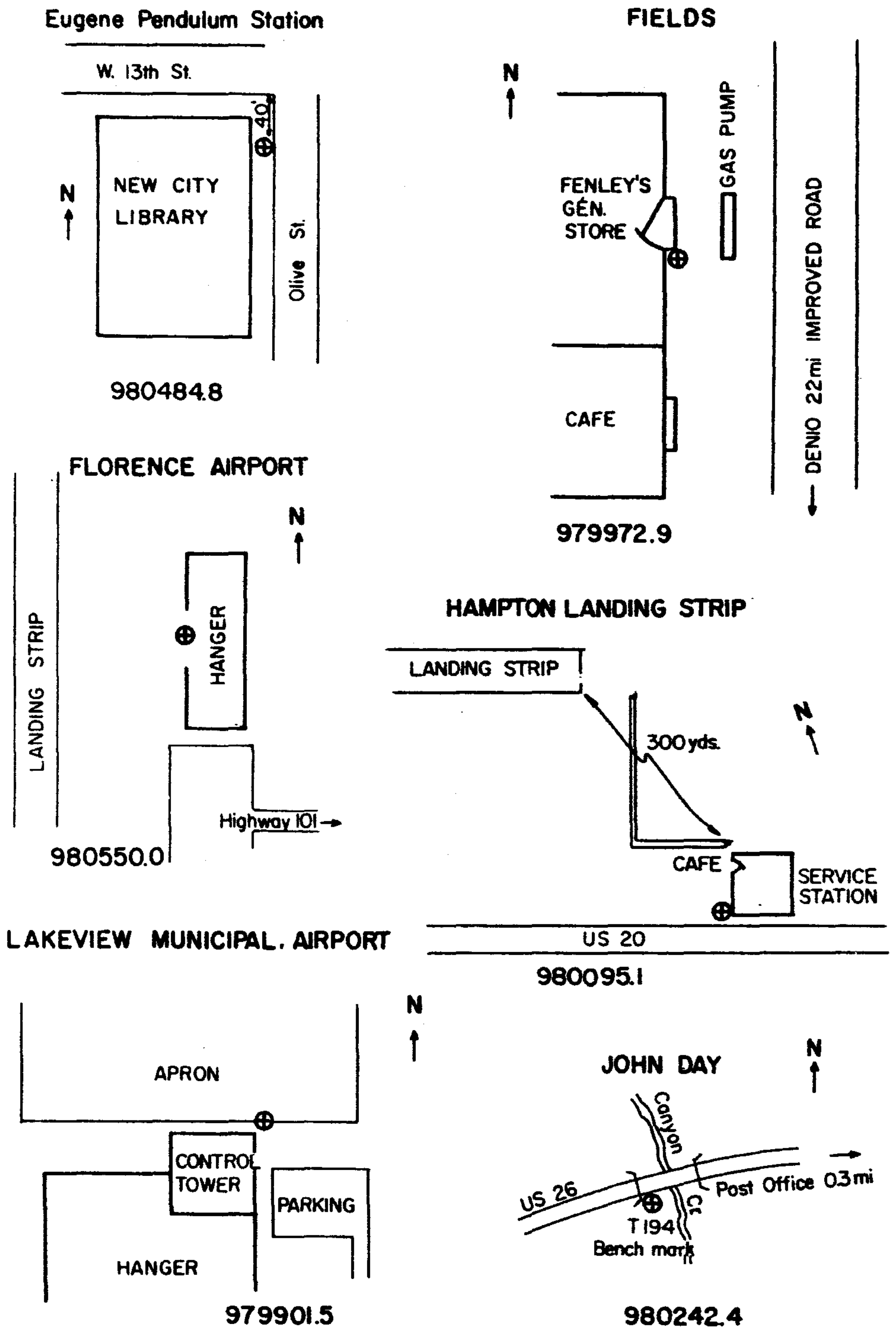
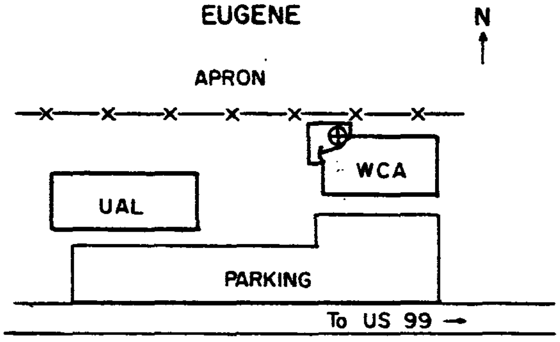


Figure 2. Plan views of gravity base stations established in Oregon. (continued on pages 54, 55, and 56)



(Figure 2, continued)

MAHON SWEET AIRPORT
EUGENE



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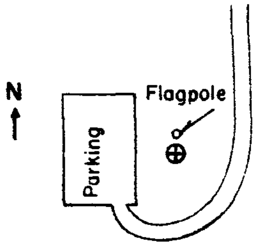
Mary's Peak



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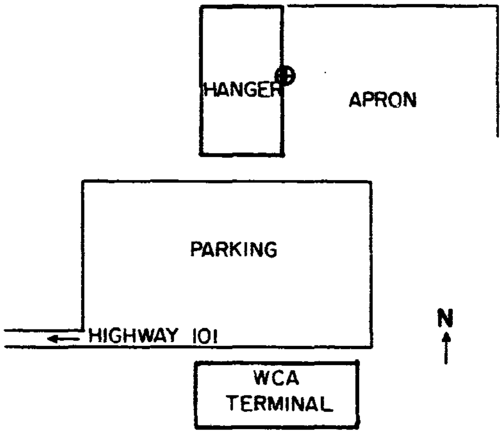
NEWPORT MUNICIPAL AIRPORT



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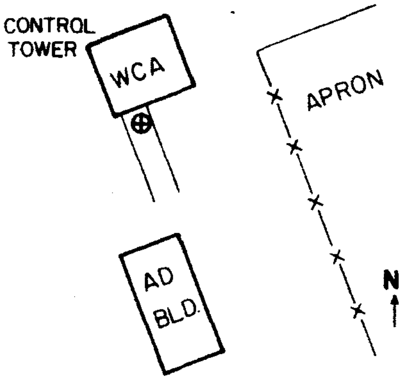
NORTH BEND MUNICIPAL AIRPORT



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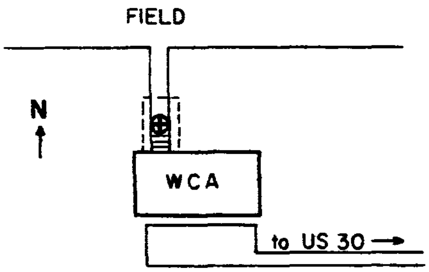
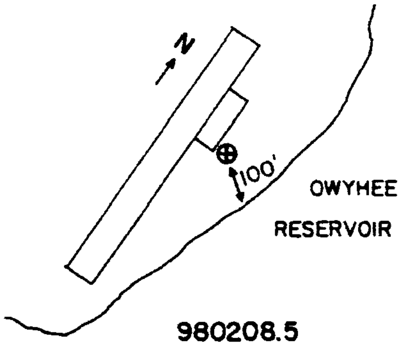
ONTARIO AIRPORT



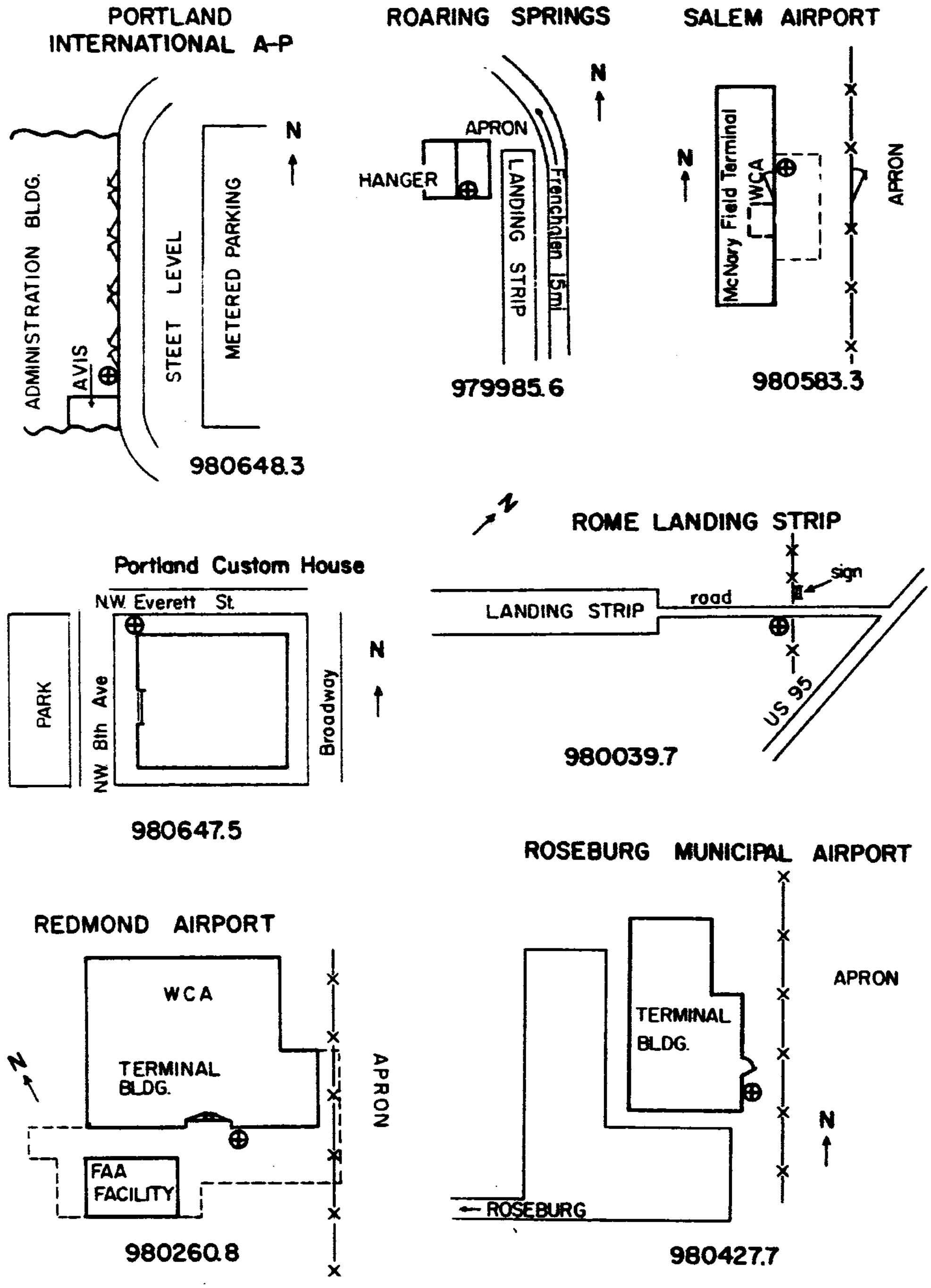
980303.5

PELICAN POINT AIRPORT



980208.5

(Figure 2, continued)



(Figure 2, concluded)