Paper G 10

ERTS-1, EARTHQUAKES, AND TECTONIC EVOLUTION IN ALASKA

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ABSTRACT

In comparing seismicity patterns in Alaska with ERTS-1 imagery, one is struck by the frequency with which earthquake epicenters fall on, or near, lineaments visible on the imagery. Often these lineaments prove to be tectonic faults which have been mapped in the field. But equally as often, existing geologic and tectonic maps show no evidence of these features. The remoteness and inacessibility of most of Alaska is responsible, in large part, for the inadequacy of the mapping. ERTS-1 imagery is filling a vital need in providing much of the missing information, and is pointing out many areas of potential earthquake hazard. Earthquakes in central and south-central Alaska result when the northeastern corner of the north Pacific lithospheric plate (roughly enclosed by the great bend in the Alaska Range near Mt. McKinley) underthrusts the continent. North of Mt. McKinley, the seismicity is continental in nature and of shallow origin, with earthquakes occurring on lineaments, and frequently at intersections of lineaments. South of Mt. McKinley, the seismicity is generally deeper and is associated with the subduction of the Pacific plate. The shallower events, however, still tend to align themselves with lineaments visible on the imagery.

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INTRODUCTION

The recent emergence of plate tectonic theory as a unifying doctrine for the earth sciences is probably the most significant breakthrough of this century in explaining the recent evolution of our planet. The manifestations of seafloor spreading -- magnetic and heat flow anomalies, oceanic ridges, arc and trench systems, volcanoes, earthquakes -- are explained with a simplicity which earlier workers would have envied. Yet, there are areas in the world which do not submit gracefully to various aspects of the theory. Central Alaska is one of those areas.

Ideally, the north Pacific plate "should" underthrust Alaska along the Aleutian trench east of Kodiak Island and the Kenai Peninsula. Indeed, this was one mechanism which was postulated for the great earthquake of 1964 (c.g., Plafker, 1972, p. 163). As a result of that earthquake, Alaska suddenly became a focal point of interest to seismologists, and the first seismographic nets in the state were established (the U.S.C.G.S. station COL near Fairbanks had been the only permanent installation in the state). With the enhanced seismographic coverage -- particularly from those stations operated by the University of Alaska -- it was possible to locate small earthquakes which had previously gone undetected, and the first clear picture of seismicity in Alaska began to emerge. It is this data which now lead us to claim that the subduction zone at the NE end of the trench-arc system does not lie offshore in the Aleutian trench, but instead extends up Cook Inlet and along the base of the Alaska Range to a point north of Mt. McKinley. The dipping interface associated with the underthrusting is clearly delineated when one examines the seismic zone in profile (Fig. 1). However, all earthquakes within the state do not occur within the subduction zone. Transmittal of stresses from around the great bend in the Alaska Range (which appears to enclose a corner of the downgoing plate) is the agent most likely responsible for a broad area of shallow seismicity in the Alaskan interior. Thus, continental Alaska can be classified into two regions on the basis of seismicity. The first of these is the area enclosed by the bend of the Alaska Range, in which earthquakes of shallow and intermediate depth (to 250 km) occur. This is separated from the shallow seismic zone of central interior Alaska by the Alaska Range, and by the Denali fault (which trends generally along the mid-line of the range). The Denali fault is therefore a transform fault along which differential movement between continent and oceanic plate is occurring.*

With this knowledge as background, it is now natural to inquire into the question of where earthquakes are likely to occur. Little can be second-guessed on the basis of past experience, because such a short period of reliable data collection has elapsed. It has been our experience that large earthquakes (magnitude 6 or greater) can occur almost randomly in the interior, with no prior warning, and insufficient data have been accumulated to even indicate that such seismic zones might exist. Geologic mapping of the state is in such a preliminary stage that it is a certainty that many seismically active faults have gone unmapped.

Therefore, it was with a great deal of anticipation with which we awaited the first ERTS imagery of this area. We were gratified, indeed, when a first look at the data showed that the larger earthquakes in the state, more often than not, fell on or near lineaments which were clearly visible on the imagery. In most cases these lineaments were not mapped as faults. It therefore appears that ERTS imagery, in the next few years, will prove to be a most important tool in assessing earthquake hazards in areas where existing seismic and geologic data are minimal. This is an especially important matter in Alaska, which will be experiencing an unprecedented rate of growth and expansion now that resource development is so vital an issue to the nation.

South-central Alaska

Figure 2 is a mosaic constructed from 19 ERTS-1 images produced on four consecutive passes of the satellite on November 2,3,4 and 5, 1972. It shows south-central Alaska with Anchorage at the head of Cook Inlet near the right center, the Kenai Peninsula at lower right center, and the Alaska Range curving across the scene from the upper right to the lower left. Several well-known structural elements are readily apparent. Two of these

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*The actual situation is not quite this simple. There are some problems with treating the Denali fault as a simple transform, but the matter will not be dealt with in this paper.

are large scale strike-slip faults which are among Alaska's most notable tectonic features. A portion of the Denali fault crosses the scene from upper right to upper left center, and it is roughly paralleled by the Lake Clark fault (which is somewhat less conspicuous) to the south. The solid circles on the key to Fig. 2 represent epicenters of earthquakes which occurred in this area during 1972. They are keyed by number to their respective parameters in Appendix I. Note that these are epicenters of earthquakes which were of magnitude 4 and larger. Many thousands of smaller events were recorded during this time. Most of the earthquakes are seen to occur in the vicinity of Cook Inlet, but it should be noted that this is largely deep-seated seismic activity related to the subduction zone, and it probably does not bear a direct relationship to lineaments which can be seen at the surface. A few earthquakes appear to be associated with the Denali fault, particularly in the vicinity of Mt. McKinley (which is casting the long shadow in the upper left quadrant), and there is an obvious clustering of earthquakes along the Lake Clark fault. Of particular interest, however, are those lineaments which are not geologically mapped as faults, but which could probably be so classified on the basis of ongoing seismicity. Particularly noteworthy are the set of sub-parallel lineaments trending off the Denali fault to the southwest, and the peculiar graben-like structure outlined by the mountains around Anchorage. The 1964 epicenter was very close to earthquakes 34 and 50 on the lineament near the right margin, although it is not clear whether or not this fault could have played a role in that earthquake. Note the extremely sharp escarpment of the Kenai Mountains which passes very close to Anchorage and the association of at least three earthquakes with this apparent fault. Even without the 1964 earthquake, this lineament should have provided Anchoragites with the admonition: Build Well! Yet it is not even mapped as a fault.

Central Interior Alaska

Figure 3 is a mosaic of 6 ERTS-1 images collected on 4 and 5 November, 1972. Fairbanks is at right center, the Yukon River enters the scene at the top, the Tanana River crosses from right to left, and the Alaska Range is at bottom right. The scene is to the north of Fig. 2 and the mosaics partially overlap (although they are of different scales). First, faults which have been previously mapped on the ground are shown as solid lines on the key. In general, these are members of the same large scale strike-slip fault system to which the Lake Clark and Denali faults belong. Although not always topographically well-defined, large offsets have occurred along most of these since the Cretaceous. Second, the lineaments indicated by dashed lines appear to be large scale faults which supplement the known set. Included in this category is the northern escarpment of the Alaska Range which appears from the imagery to be a normal fault with considerable vertical displacement, although some workers believe that it is a fold feature. Finally, a very sharp set of conjugate lineaments is shown on the key as dotted lines. These intersect at an angle of about 55° and appear to be the result of compressive stress in an outward direction from around the bend of the Alaska Range. The angle of 55° is roughly the dihedral angle at which most brittle substances would be expected to fracture under compressive stress, with left-lateral offset on one set of fractures, and right-lateral offset on the other. The persistence of these features over large areas implies that they are continuous beneath the alluvium of the Tanana River valley.

The circles on the key relate to epicenters of the largest earthquakes to occur within the mapped area within recent years. The numbers correlate the earthquakes with their respective parameters which are given in Appendix II. It is significant that these have tended to occur at intersections of lineaments visible on the imagery. Focal mechanism studies have shown that the earthquake on the conjugate set of lineaments (number 2) was the result of left-lateral slippage on the prominent north-south trending fault, in agreement with the model proposed above. The Fairbanks earthquake of 1967 (number 1) appears to have been the result of left-lateral slippage on the NE-SW trending lineament -- a perplexing situation and one which indicates that the stress trajectories must curve across the region.

Much of the area of the mosaic will be under development in the years ahead. In particular, the trans-Alaska pipeline will cut across nearly every one of the major lineaments in the northeast quadrant. Since so little is presently known of the seismicity of these areas over long periods of time, we are compelled to regard each of these lineaments (and those in Fig. 2) as being potential sites for future earthquakes, particularly in view of the fact that some of them have produced sizeable events in only the brief period since 1967.

Reference

Plafker, George, Tectonics, The Great Alaska Earthquake of 1964, Seismology and Geodesy, pp. 113-174, Committee on the Alaska Earthquake of the Division of Earth Sciences, National Research Council, National Academy of Sciences, 1972.

APPENDIX I

The following table lists, by number, all the epicenters which are plotted on Fig. 2. All data in the table were produced by the University of Alaska seismology program, except those accompanied by an asterisk (*), for which the National Oceanographic and Atmospheric Administration (NOAA) was the source.

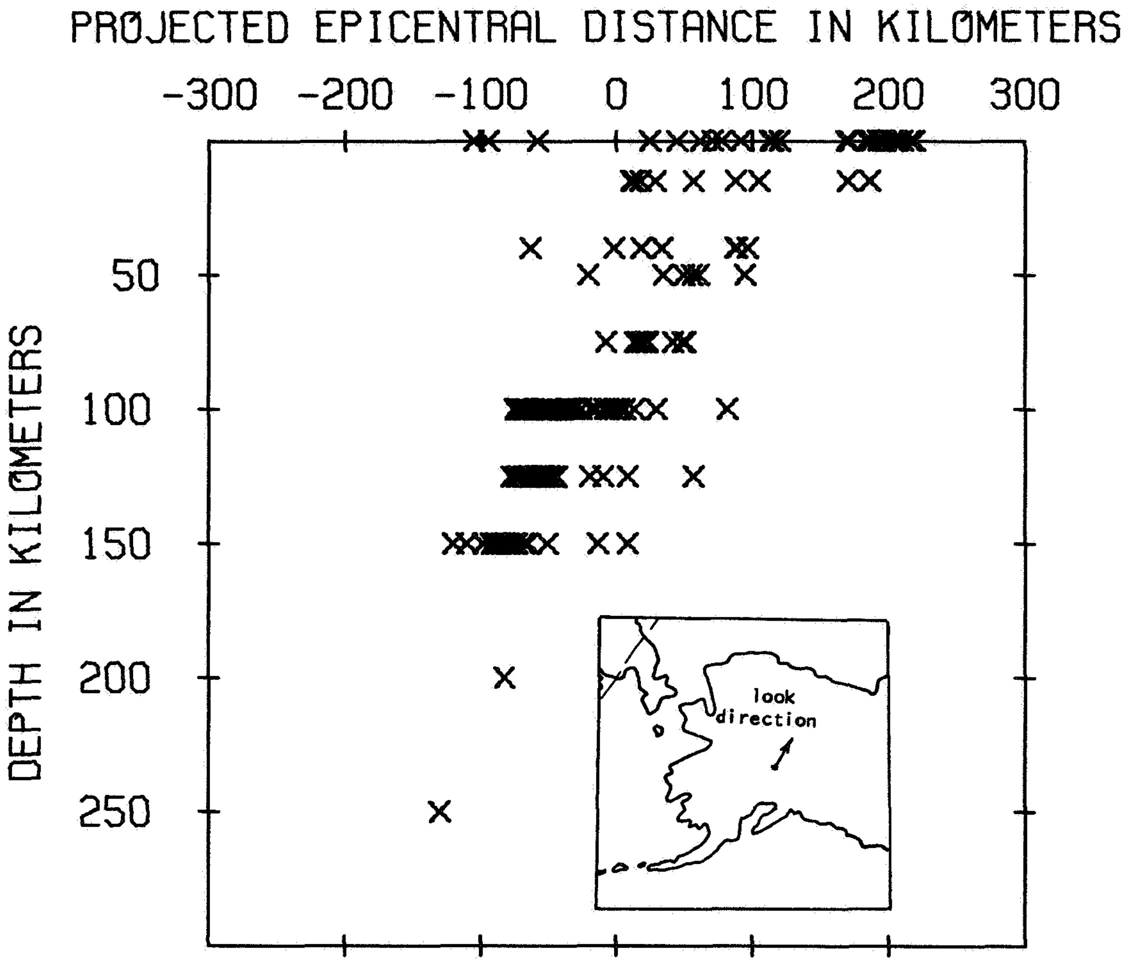
Date (1972)	Latitude (N)	Longitude (W)	Magnitude
1. Jan 2	59.3	153.6	4.4
2. Jan 9	59.5	156.6	4.0
3. Jan 19	59.4	156.9	4.3
4. Jan 24 *	59.6	151.4	4.0
5. Feb 5 *	60.3	153.8	4.6
6. Feb 13 *	59.9	154.2	4.9
7. Feb 16	59.5	152.9	4.3
8. Feb 25	61.3	149.4	4.0
9. Feb 27	59.2	151.6	4.4
10. Feb 29	63.2	150.5	4.0
11. Mar 1 *	59.6	152.8	4.6
12. Mar 7	60.0	155.3	4.0
13. Mar 12 *	64.1	148.4	4.2
14. Mar 12	61.6	147.7	4.0
15. Mar 14	60.8	152.3	4.0
16. Mar 21	60.1	150.3	4.0
17. Mar 23	59.7	153.2	4.3
18. Mar 25	59.8	155.6	4.0
19. Mar 25	59.3	155.3	4.1
20. Mar 28 *	59.8	153.4	4.3
21. Mar 29 *	59.9	153.1	5.1
22. Apr 2 *	59.9	153.6	4.9
23. Apr 5	61.4	151.9	4.0
24. Apr 7 *	60.1	152.8	5.1
25. Apr 9	64.0	150.9	4.5
26. Apr 9	61.6	151.0	4.1
27. Apr 11 *	62.0	150.4	4.2
28. Apr 15	60.8	153.6	4.1
29. Apr 16	63.4	147.6	4.6
30. Apr 16	63.5	147.6	4.1
31. Apr 19	58.7	155.6	4.1
32. Apr 20 *	60.2	152.1	4.7
33. Apr 20 *	59.9	153.6	4.5
34. Apr 25	61.1	147.1	4.0
35. Apr 25 *	62.0	147.8	4.6
36. Apr 28 *	63.6	149.9	4.7
37. May 7	61.1	152.1	4.1
38. May 8	59.6	155.7	4.1
39. May 8	58.8	153.0	4.1
40. May 14	62.4	151.1	4.0
41. May 14	61.8	150.3	4.1
42. May 19	59.6	152.9	4.1

Date (1972)	Latitude (N)	Longitude (W)	Magnitude
43. May 20	59.6	152.9	5.2
44. Jun 1	59.6	155.1	4.0
45. Jun 10	59.1	155.6	4.1
46. Jun 14	61.0	152.5	5.2
47. Jun 16	59.3	152.3	4.2
48. Jun 18	62.6	152.7	4.7
49. Jun 20	59.5	152.7	5.1
50. Jun 22	61.4	147.5	4.6
51. Aug 6	60.0	149.2	4.0
52. Aug 9	58.7	154.5	4.1
53. Aug 12	61.4	149.8	4.0
54. Aug 17	59.4	152.6	4.2
55. Aug 19	59.1	153.3	4.2
56. Aug 22	59.8	152.2	4.1
57. Aug 23	58.4	153.2	5.5
58. Sep 3 *	59.7	149.1	4.7
59. Sep 11 *	59.6	148.9	5.1
60. Oct 1	62.7	149.1	5.2
61. Oct 1	59.8	153.3	4.7
62. Oct 20	60.0	152.4	4.2
63. Oct 21	63.2	151.1	5.4
64. Nov 19	60.9	153.1	4.6
65. Nov 21	62.2	149.7	4.1
66. Nov 22	59.6	152.4	4.1
67. Nov 25	58.6	152.2	4.3
68. Nov 28	59.7	153.5	5.1
69. Dec 3	59.8	154.7	4.0
70. Dec 3	58.6	155.2	4.4
71. Dec 4	59.8	154.8	4.2
72. Dec 15	60.3	151.2	5.0
73. Dec 18	60.8	153.1	5.6
74. Dec 29	61.6	151.3	4.5

APPENDIX II

Listing of earthquakes plotted on Figure 3.

Date	Latitude (N)	Longitude (W)	Magnitude
1. 21 Jun 67	64.8°	147.4°	6.0
2. 29 Oct 68	65.4°	150.0°	6.5
3. 21 Jun 69	65.2°	147.6°	4.6
4. 9 Jun 70	64.9°	148.7°	4.2
5. 15 Aug 72	65.2°	148.7°	5.1



PROJECTION ORIGIN: 62.54N 150.08W

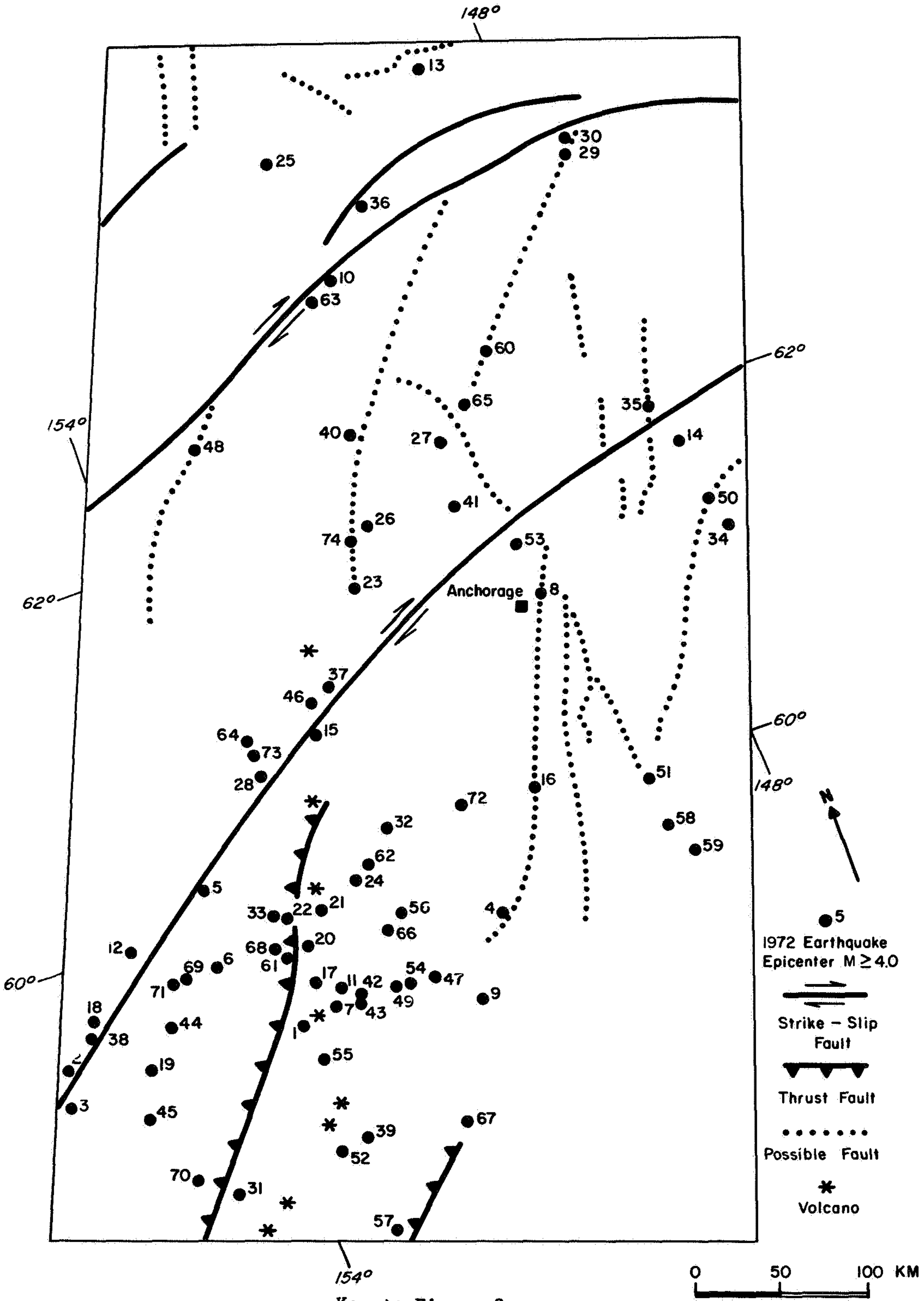
LIMITING ORIGIN: 62.96N 149.74W

AZIMUTH OF PROJ PLANE: 20 DEGREES

NUMBER OF EVENTS PLOTTED: 162 OF 1847

Figure 1

Figure 2



Key to Figure 2

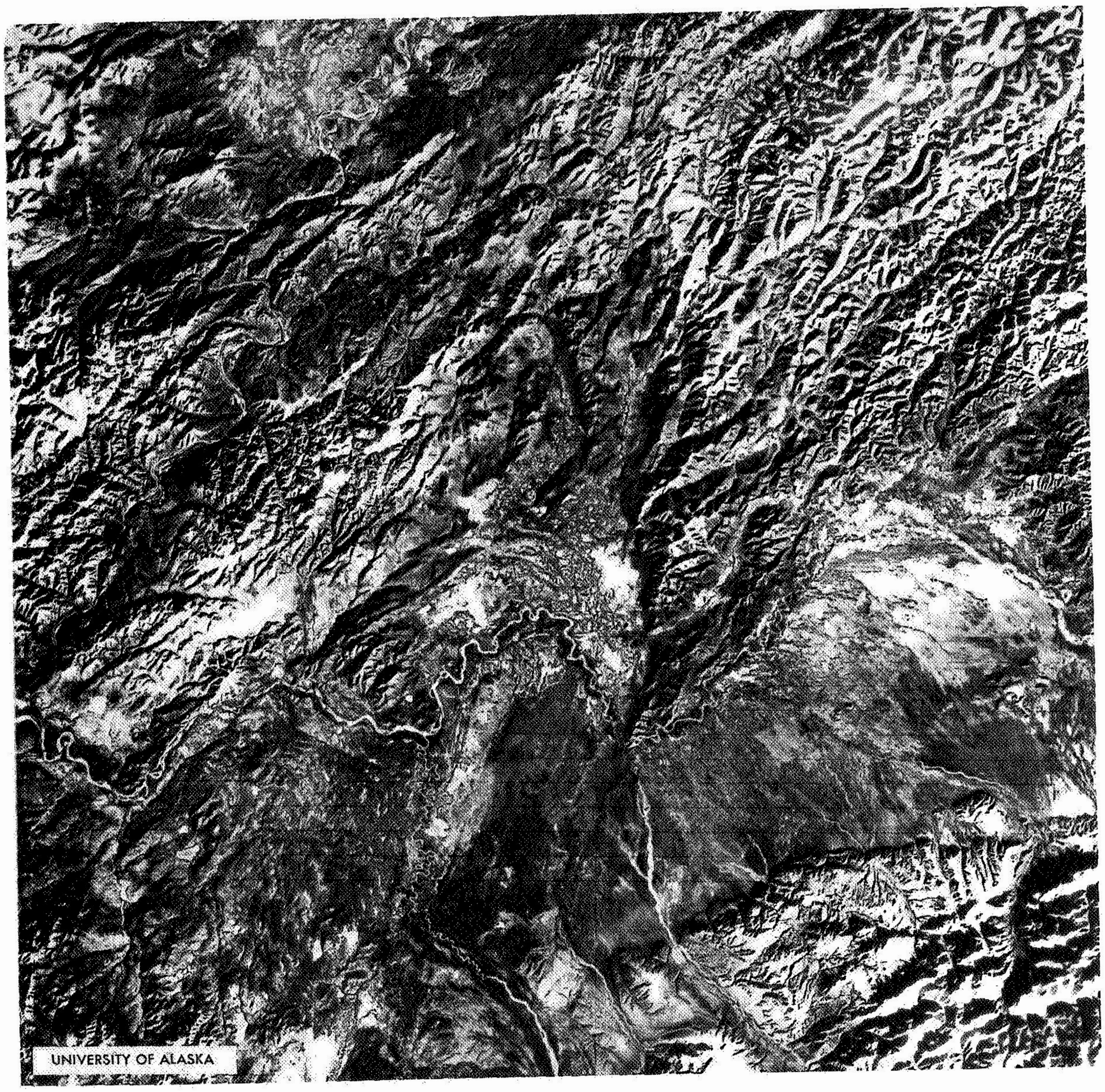
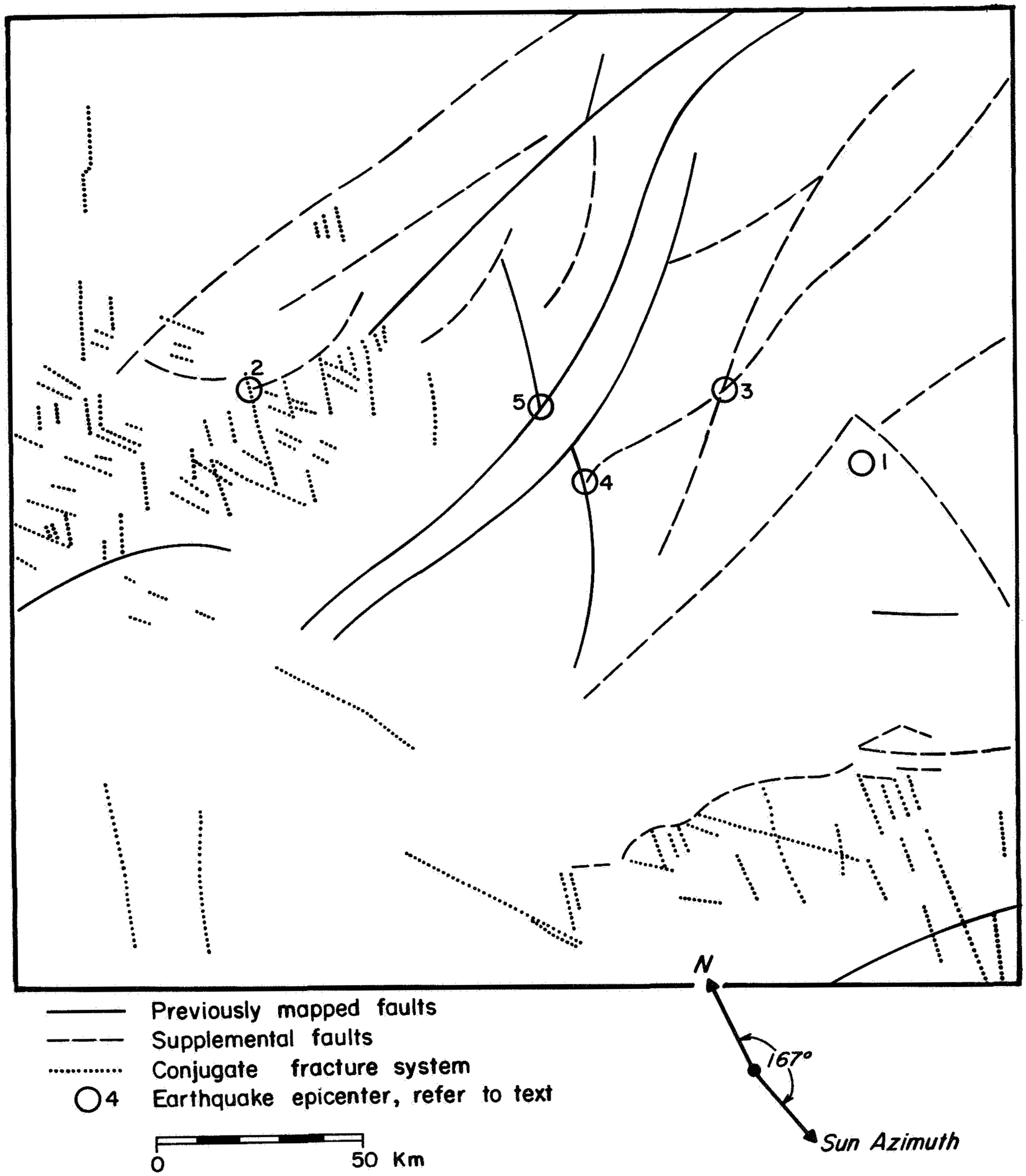


Figure 3



Key to Figure 3