Observation of Gravity to Reveal a Buried Fault Associated with the Fukui Earthquake

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Abstract

Gravity observation was carried out in and around the Fukui plain to locate a buried fault associated with the Fukui Earthquake on June 28, 1948.

By a two-dimentional analysis of the Bouguer anomaly, a fault with a vertical offset of 200 m was revealed beneath the fissure zone that was formed at the time of the Fukui Earthquake. This offset value suggests that the Fukui Earthquakes other than the event in 1948 took place repeatedly in the past and were associated with the present fault.

1. Introduction

The Fukui Earthquake occurred on June 28, 1948 with a magnitude of 7.3 in Fukui prefecture[1]. The number of persons killed was 3769 and more than twenty thousand persons were injured[2]. Houses collapsed and railway tracks and roads seriously damaged, especially near the epicentral area, where 100% of the houses totally collapsed[2].

No active fault was found in and around the Fukui plain by eye witness, whereas many cracks and fissures were found in the plain, and some of them formed fissure zones of a few kilometers long.[1] The existence of an underground fault associated with the event was pointed out by precise leveling surveys soon after the earthquake.[1] The results show a subsidence of the ground in the western part of the plain, and an uplift in the eastern part[1]. A deformation boundary that separates these two parts strikes north to slightly west, about 3 km west of Maruoka town. The maximum value of the relative vertical movement between the neighboring leveling points across the boundary was 70 cm[1]. A focal mechanism study of this event shows that the earthquake was of a strike-slip type, one of the nodal lines trending N 10°E[3]. This mechanism agrees well with the strike of the boundary mentioned above. Kanamori (1973)[4] showed a fault model by comparing synthetic seismograms with the records obtained at the Abuyama Seismological Observatory. He stated that the fault plane was vertical with an area of $30\times13\ km^2$. But he also pointed out the possibility of the fault dipping steeply to the east.

The recurrence intervals of large earthquakes in the Japanese islands might be between 1000 and 10000 years[5,6], so it is possible that the previous Fukui Earthquakes took place repeatedly associated with the same fault as the present event in

1948. If so, the accumulated dislocation of the vertical component would exceed some 100 m in these one million years or so, and the offset is enough to be detected by a sensitive gravimeter. Kono et al. (1982)[7] and Kono et al. (1982)[8] have revealed a Bouguer anomaly map over the northern part of central Japan by compiling their own data and others'. Kono et al. (1981)[9] showed a possible underground structure in the region of the Fukui Earthquake. But their observation points were not distributed densely enough to conclude the accumulation of vertical dislocations by repeated earthquakes. The aims of the present work are to find out the location of the fault and to estimate the accumulated dislocation by gravity observations at densely distributed points.

2. Observation and Data Processing

Observations were carried out twice at the points in **Fig. 1.** The first one was in August 1980 to find a rough image of the plain and the buried fault. The other was in July 1982 to delineate a more detailed structure. Observation points are grouped into O, E, K, S and F lines symbolizing Oono city, Eiheiji-temple, Katsuyama city, Sabae city and the fault itself, respectively. Observations along

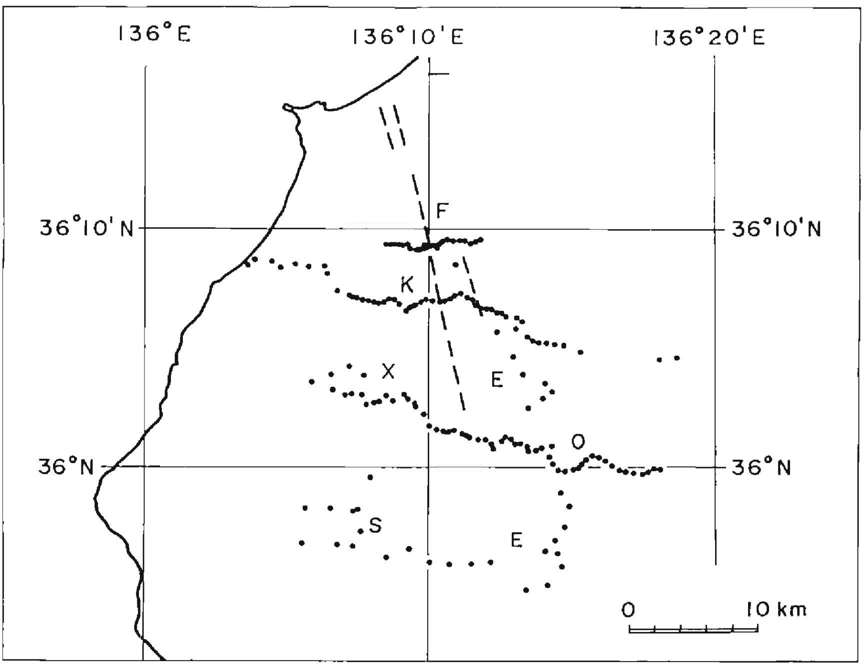

Fig. 1. Map of observation points. They are grouped into F, K, E, O, S and X lines. Dashed lines indicate the locations of earthquake faults after the Research Group for Active Faults[10]. These are recognized as active faults by the distribution of cracks and fissures and by the results of the precise leveling surveys soon after the Fukui Earthquake.

F line alone were carried out in 1982, and the others in 1980.

The complete Bouguer anomalies at the observation points are listed in **Table 1**, together with their locations, heights and correction terms. The line of X is also shown in **Fig. 1** as the westward extended route of O line, but their values are omitted from the table, since the results have already been treated with in another paper[7]. K line and X-O lines traverse over the fault, and E and S lines are additional routes to study the general features of the region. The observation points were chosen from the bench marks, leveling points, and spot heights in precise topographic maps, such as the Topographic maps of 1:25000 issued by the Geographical Survey Institute (GSI) and Town planning maps of the town offices. The distance from one observation point to another was settled on 500 m, if possible. The heights of the observation points are presented in these maps with a precision of 10 cm. But the accuracy which can be expected for the leveling points and spot heights may actually be 1 m or so, since at the time of observation it was often hard for us to find the very points which were plotted in the maps. In such cases, we chose a point that might be very near the plotted place, and used the value in the map as the height of the observation point.

Two LaCoste & Romberg gravimeters (Model G) were employed. One is G–348 of Kanazawa University, and the other G–210 of University of Tokyo. A series of observations for G–348 started from the room 166 in the Department of Earth Sciences, Faculty of Science, Kanazawa University, where the gravity value had been determined as

$$g = 979\ 857.990\ \text{(mgal)}.$$

And for G–210, it started from the First Order Gravity Station at the Fukui Local Meteorological Observatory, and its gravity value was listed in JGSN 75[11] as

$$g = 979\ 838.10\ \text{(mgal)}.$$

The observation was closed everyday at a bench mark near the observation lines. The whole series was terminated at the starting point and the observation was closed. The Normal Gravity was calculated using the formula by the Geodetic Reference System 1967[12]:

$$\gamma = 979\ 031.85\ (1 + 0.005\ 278\ 895\ \sin^2\psi + 0.000\ 023\ 462\ \sin^4\psi)\ \text{(mgal)},$$

where ψ is the geographical latitude. The atmospheric correction term (Atm) was calculated by the following equation,

$$Atm = 0.87 - 0.00965 \times 10^{-3}\ h\ \text{(mgal)},$$

where h is the height of the observation point in meters.

The vertical gradient of gravity was assumed to be 0.3086 mgal/m, and the Bouguer correction was made by assuming 2.67 g/cm^3 for the mean density. The complete Bouguer anomaly was carried out by a computer program developed in

Kanazawa University (Kubo, 1980[13] and Kono & Kubo, 1983[14]), which basically referred to Hagiwara (1967)[15]. Thus the complete Bouguer anomaly is represented by

$$\Delta g_0'' = g - \gamma + Atm + 0.3086h - 2\pi G\rho h + Tr,$$

where G, ρ and Tr denote the Gravitational constant, assumed density for the Bouguer correction and the terrain correction term, respectively. The gravity values measured by the two gravimeters at the same points showed 0.1 mgal or less difference, which might be caused from the differences of the scale values. But we neglected this since the differences were less than the accuracy of terrain correction terms.

3. Results and Discussions

In **Fig. 2**, the east-west profiles of the Bouguer Anomaly for K and X-O lines

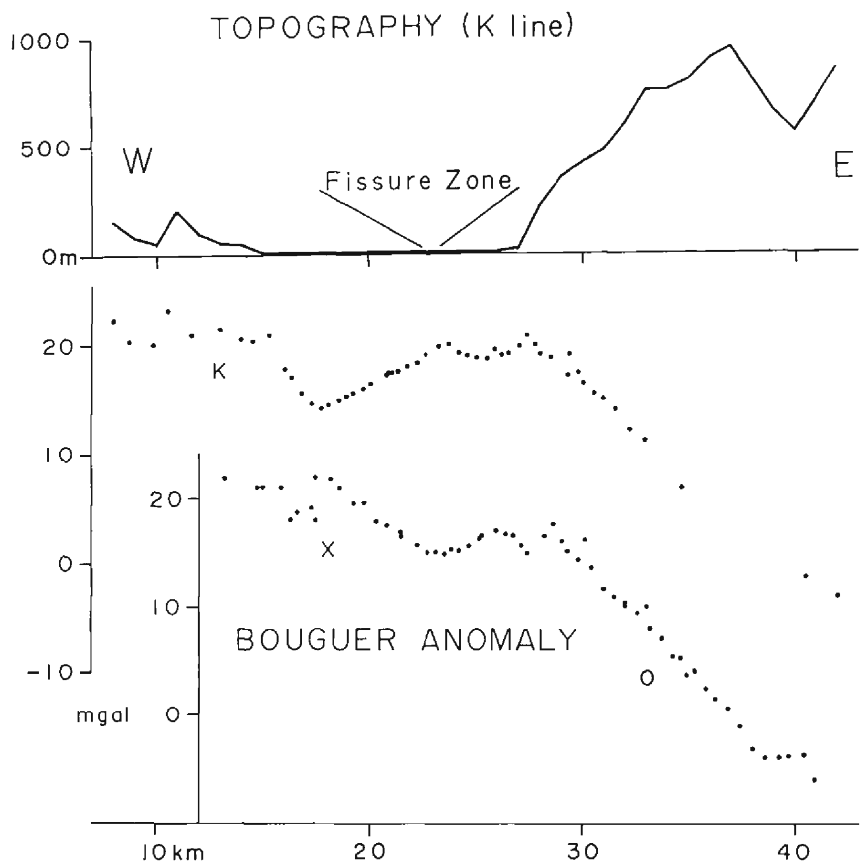

Fig. 2. The Bouguer anomalies along K line and X-O lines with topographic profile along K line. A fault should exist beneath the fissure zone rather than at the east end of the plain.

are plotted. The horizontal axis is the distance from 136°E. The topographic cross section along K line is also shown in **Fig. 2**. A common pattern can be seen in the two profiles; in the western half, the values of the Bouguer anomaly are positive, slightly decreasing towards the east and abruptly descending to negative values at a ratio of 1.6 to 1.9 mgal/km in the eastern part. These patterns can be explained by the undulation of the Moho or Conrad discontinuity or of the upper boundary of the granitic layer, as is mentioned by Furuse & Kono (1982)[16]. A trough of the Bouguer anomaly can be seen in the western half of the K and X-O profiles, with a magnitude of several mgals. The minimum value in the trough are observed in the midst of the Fukui plain, where Tertiary bed rocks are thickly covered by alluvial, diluvial and Tertiary sediments. The maximum thickness of the alluvium, however, is estimated to be about 30 m, which brings about only an 0.5 mgal change to the Bouguer anomaly, so the main part of the trough is due to deeper structures. The ascending Bouguer anomaly, which is seen between 17 to 27 km in the eastern part of the trough along K line, suggests the existence of a fault. This fault should be

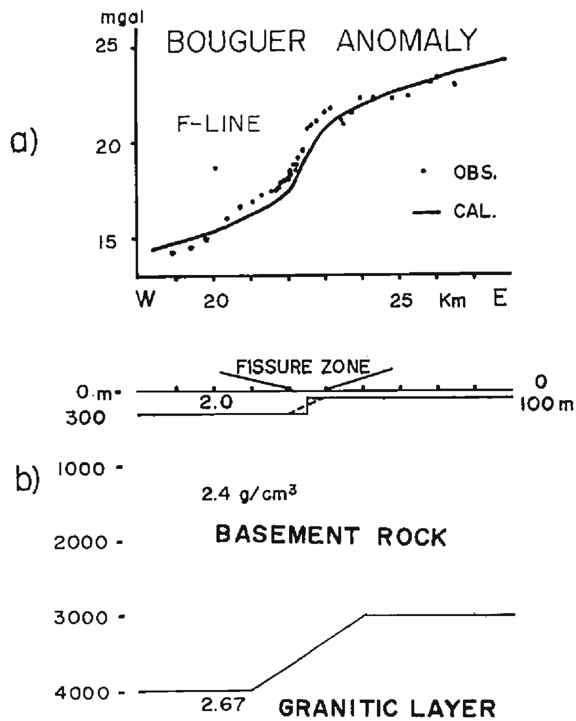

Fig. 3. a) Plots of the observed Bouguer anomalies along F line with synthetic ones calculated on the underground structure shown in b).
b) A possible underground structure as a two-dimensional solution for the observed Bouguer anomalies. Beneath the fissure zone there exists a fault with a vertical offset of 200 m. Although the dashed line is a possible structure (other structures are also possible), some abrupt change at the boundary between the basement rock and sediment is needed to explain the observed data for any one of the solutions.

located at a distance of 22 or 23 km, rather than at 27 or 28 km where the active fault of Matsuoka lies.

Our second observation in 1982 was intended to find a more precise location of the fault and to estimate its vertical offset. Forty observation points were chosen and they formed F line at an average interval of 200 m, about 4 km north to the K line. This line lies mainly in the Fukui plain, and the difference of heights between F1 and F35 which are surrounded by rice fields is within 5 m. The Bouguer anomaly is shown in **Fig. 3(a)**, in which we can find a larger gradient at the distance range of 22 to 23 km than in the plots of K line. This must be attributed to a shallow structure like the boundary shape of sediments, which could not be revealed without observations along F line. A possible underground structure is shown in **Fig. 3(b)**, and the synthetic Bouguer anomaly curve is presented in the upper figure, calculated by a two-dimensional method after Talwani et al. (1959)[17]. The model structure is derived as follows. A ramp shape structure associated with the granitic layer was taken to explain the increase of the Bouguer anomaly towards the east. The high gradient is supposed to be due to a fault which appeared as a step in the Tertiary bed rocks. The shallow sediments are assumed to consist of one layer with a density of 2.0 g/cm^3, although they consist of the alluvial, diluvial and Tertiary deposits. This treatment is justified because the effect of thickness of the alluvium to the gravity field was very small. Furthermore the boundary between the diluvial and Tertiary sediments has not been clearly shown by boring data. The depth to the upper surface of the granitic layer was fixed at 3 to 4 km, the values of which are often used in the hypocenter determination of microearthquakes in and around the present region. But this boundary can be shifted vertically without yielding significant modifications on the calculated gravity. Thus, we assumed a three-layer model with densities of 2.0, 2.4 and 2.67 after Furuse & Kono (1982)[16], and looked for a suitable model by trial and error. A solution was found as is shown by the solid lines in **Fig. 3(b)**, by which the calculated Bouguer anomaly agrees well with observed data.

The solution, however, is not unique as is often the case in underground structure analysis. For example, the step in the basement rock and sediments—that is the fault we are now seeking for—can be replaced by a slope as is drawn by the dashed line in **Fig. 3**. This replacement merely requires adding 0.3 mgal to the synthetic curves near the fault and smaller values elsewhere. The vertical offset was obtained as 200 m on the above assumption of densities, but it can be reduced to 100 m when the density assumptions are changed within possible ranges.

Another possible case is that the surface of the granitic layer is perfectly flat, and that the Bouguer anomaly is fully caused by the upper boundary shape of the basement rock. Then the resultant offset would be greater than in the case shown in the figure. We have, so far, not taken into account the general tendency of 0.5 to 1.0 mgal/km decreasing towards the east, which may be due to the Conrad or Moho discontinuity. The correction for this tendency, however, can be explained by increasing the amount of offset. After all, the model proposed here is a typical solution and it states that a fault with 200 m offset exists beneath the fissure zone that was found soon after the Fukui Earthquake.

The fact has not yet been considered that the gradient in the problem is highest in F line and is smaller in K or X-O lines. This is left for further studies.

4. Conclusions

A gravity survey was carried out in and around the Fukui plain, and the Bouguer anomalies were calculated to complete the gravity map over the northern part of central Japan. A fault was revealed by analyzing the anomalies, which may have been formed by a series of Fukui Earthquakes. The accumulated vertical displacement of this fault is estimated to be 200 m with an ambiguity of factor 2. We may evaluate the recurrence interval of the earthquakes by the following assumptions:

a) The earthquake sequence started within a million year span of time, and they have occurred repeatedly with equal intervals since then.

b) Each event was generated from the present fault with the same vertical dislocation ($\sim$1 m).

c) Only the earthquakes assumed here have attributed to the vertical displacement accumulation of this fault.

A simple calculation leads to the conclusion that the recurrence interval of the Fukui Earthquakes associated with the present fault is 5000 years. We must, however, be very careful when using this value since it is a rough estimation derived only from the fault presently under discussion.

Acknowledgements

We thank the staff of the Earthquake Research Institute, University of Tokyo, who kindly allowed us to use their gravimeter. We also thank the graduate students at the time of this investigation, N. Furuse and M. Sunami for helpful suggestions and assistances in data processing. Thanks are also due to S. Kishi, a student of Kanazawa University at the time for cooperation in observation. We are thankful to N. Hurukawa of Kyoto University and other members of the Group for Surveying the Fukui Earthquake Fault for discussions and encouragements.

Computations were carried out at the Data Processing Center of Kanazawa University (FACOM M-170), and also at the Computer Center of Shizuoka University (HITAC 8250).

Table 1. Lists of the Bouguer anomalies. Locations of the observation points with their heights, correction terms and some memos are also represented.

LOCATION (NO.)	(NAME)	LATITUDE (DEG.)	LONGITUDE (DEG.)	HEIGHT (M)	GRAVITY OBSERVE	GRAVITY NORMAL	GRAVITY ANOMALY OB-NOR	GRAVITY ANOMALY FREE-AIR	GRAVITY ANOMALY BOUGUER	CORRECTIONS FREE-AIR	CORRECTIONS BOUGUER	CORRECTIONS EARTH TIDE	CORRECTIONS TERRAIN	CORRECTIONS ATMOS	DATE Y	DATE M D H M	* FRC (*10)
					979000.	979000.											
1	S-01 (BM910-1)	35.9377	136.2115	19.60	823.131	812.983	10.148	17.065	16.589	6.049	-2.194	-0.067	1.719	.868	80.	8. 9.16.38.	0
2	S-02 (BM008-424)	35.9447	136.1843	19.50	820.822	813.584	7.238	14.124	12.430	6.018	-2.183	-0.074	0.489	.868	80.	8. 9.16.54.	0
3	S-03 (BM008-421)	35.9700	136.1838	23.10	827.111	815.758	11.353	19.349	17.209	7.129	-2.586	-0.082	0.446	.868	80.	8. 9.17.14.	0
4	S-04 (BM008-418)	35.9940	136.1977	10.10	835.686	817.821	17.865	21.851	21.239	3.117	-1.131	-0.088	0.518	.869	80.	8. 9.17.42.	0
5	S-05	35.9725	136.1872	17.10	830.956	815.973	14.983	21.128	19.668	5.277	-1.914	-0.089	0.454	.868	80.	8. 9.17.57.	0
6	S-06	35.9548	136.1819	18.70	827.625	814.452	13.173	19.812	18.204	5.771	-2.093	-0.089	0.486	.868	80.	8 .9 18.12.	0
7	0-01 (SHIMOSHIN BR.)	36.0180	136.3137	41.10	824.124	819.884	4.240	17.789	16.617	12.683	-4.601	0.127	3.429	.866	80.	8.10.10.13.	0
8	0-02	36.0212	136.3177	41.90	824.237	820.159	4.078	17.874	17.706	12.930	-4.691	0.131	4.523	.866	80.	8.10.10.20.	0
9	0-03 (TAKADA BR.)	36.0193	136.3228	44.10	823.633	819.996	3.637	18.112	16.143	13.609	-4.937	0.135	2.968	.866	80.	8.10.10.27.	0
10	0-04	36.0162	136.3253	47.50	822.081	819.729	2.352	17.876	15.195	14.658	-5.318	0.139	2.637	.865	80.	8.10.10.37.	0
11	0-05	36.0163	136.3313	49.70	820.697	819.738	0.959	17.162	14.390	15.337	-5.564	0.143	2.792	.865	80.	8.10.10.46.	0
12	0-06	36.0142	136.3353	68.70	818.773	819.557	-0.784	21.280	16.251	21.201	-7.691	0.146	2.662	.863	80.	8.10.10.56.	0
13	0-07	36.0115	136.3377	59.70	816.569	819.325	-2.756	16.532	13.698	18.423	-6.683	0.149	3.850	.864	80.	8.10.11. 5.	0
14	0-08 (OHKUBO BR.)	36.0112	136.3442	55.40	813.771	819.299	-5.528	12.433	11.685	17.096	-6.202	0.150	5.454	.865	80.	8.10.11.13.	0
15	0-09	36.0132	136.3497	57.40	813.231	819.471	-6.240	12.338	10.994	17.714	-6.426	0.151	5.082	.864	80.	8.10.11.21.	0
16	0-10	36.0138	136.3565	65.70	811.122	819.523	-8.401	12.738	10.402	20.275	-7.355	0.152	5.019	.864	80.	8.10.11.33.	0
17	0-11 (KAMI SHIN BR.)	36.0045	136.3562	72.80	807.300	818.723	-11.423	11.906	10.160	22.466	-8.150	0.152	6.404	.863	80.	8.10.11.47.	0
18	0-12	35.9997	136.3667	75.90	806.501	818.311	-11.810	12.476	10.091	23.423	-8.497	0.150	6.112	.863	80.	8.10.12. 1.	0
19	0-13	35.9960	136.3627	79.50	806.399	817.993	-11.594	13.802	9.531	24.534	-8.900	0.149	4.629	.862	80.	8.10.12. 8.	0
20	0-14 (MIYAMA ST.)	35.9958	136.3685	82.60	804.616	817.975	-13.359	12.993	8.116	25.490	-9.247	0.138	4.370	.862	80.	8 10.12.40.	0

Table 1. Continued.

LOCATION (NO.)	(NAME)	LATITUDE (DEG.)	LONGITUDE (DEG.)	HEIGHT (M)	GRAVITY OBSERVE	GRAVITY NORMAL	GRAVITY ANOMALY OB-NOR	GRAVITY ANOMALY FREE-AIR	GRAVITY ANOMALY BOUGUER	CORRECTIONS FREE-AIR	CORRECTIONS BOUGUER	CORRECTIONS EARTH TIDE	CORRECTIONS TERRAIN	CORRECTIONS ATMOS	DATE Y	DATE M D H M	* FRC (*10)
					979000.	979000.											
21	O-15 (SAKAI TERA BR.)	35.9965	136.3745	84.90	802.356	818.036	-15.680	11.382	7.188	26.200	-9.505	0.134	5.310	.862	80.	8.10.12.49.	0
22	O-16	35.9977	136.3800	88.90	799.675	818.139	-18.464	9.832	5.549	27.435	-9.952	0.127	5.669	.861	80.	8.10.13. 1.	0
23	O-17	36.0010	136.3840	96.30	797.370	818.423	-21.053	9.526	5.290	29.718	-10.781	0.122	6.544	.861	80.	8.10.13.10.	0
24	O-18 (YAKUSHI STN.)	36.0025	136.3870	94.10	796.429	818.551	-22.122	7.778	3.733	29.039	-10.535	0.116	6.490	.861	80.	8.10.13.19.	0
25	O-19	36.0055	136.3915	100.50	795.510	818.809	-23.299	8.575	4.113	31.014	-11.251	0.108	6.789	.860	80.	8.10.13.30.	0
26	O-20	36.0052	136.3975	105.60	794.058	818.784	-24.726	8.722	2.415	32.588	-11.822	0.101	5.515	.860	80.	8.10.13.40.	0
27	O-21	36.0028	136.4023	108.50	792.946	818.577	-25.631	8.712	1.499	33.483	-12.147	0.094	4.934	.860	80.	8.10.13.48.	0
28	O-22	35.9985	136.4088	117.10	790.166	818.208	-28.042	8.954	0.619	36.137	-13.109	0.087	4.774	.859	80.	8.10.13.57.	0
29	O-23	35.9975	136.4148	122.30	787.996	818.122	-30.126	8.474	-1.193	37.742	-13.692	0.080	4.024	.858	80.	8.10.14. 5.	0
30	O-24	35.9967	136.4217	129.40	784.531	818.053	-33.522	7.268	-3.231	39.933	-14.486	0.072	3.987	.858	80.	8.10.14.15.	0
31	O-25	35.9957	136.4277	136.50	782.569	817.967	-35.398	7.583	-3.907	42.124	-15.281	0.063	3.791	.857	80.	8.10.14.24.	0
32	O-26	35.9942	136.4350	146.90	780.628	817.838	-37.210	8.979	-3.994	45.333	-16.445	0.054	3.472	.856	80.	8.10.14.34.	0
33	O-27	35.9957	136.4405	157.00	778.988	817.967	-38.979	10.326	-3.811	48.450	-17.576	0.048	3.439	.855	80.	8.10.14.41.	0
34	O-28	35.9982	136.4485	182.50	773.780	818.182	-44.402	12.770	-3.663	56.319	-20.431	0.038	3.998	.852	80.	8.10.14.52.	0
35	O-29 (R158 TUNNEL)	35.9973	136.4540	199.60	768.602	818.105	-49.503	12.945	-6.073	61.597	-22.345	0.030	3.328	.851	80.	8.10.15. 0.	0
36	K-01 (BM5246)	36.0768	136.4670	100.10	797.914	824.942	-27.028	4.724	-2.826	30.891	-11.206	-0.058	3.657	.860	80.	8.10.16.49.	0
37	K-02 (BM5247)	36.0743	136.4495	90.60	800.935	824.726	-23.791	5.029	-1.191	27.959	-10.143	-0.066	3.923	.861	80.	8.10.17. 2.	0
38	K-03 (BM5250)	36.0797	136.3855	60.50	815.821	825.191	-9.370	10.165	7.077	18.670	-6.773	-0.080	3.685	.864	80.	8.10.17.34.	0
39	K-04 (BM5251)	36.0850	136.3658	52.20	822.659	825.647	-2.988	13.986	11.428	16.109	-5.844	-0.085	3.286	.865	80.	8.10.17.52.	0
40	K-05	36.0853	136.3585	48.40	824.089	825.673	-1.584	14.218	12.381	14.936	-5.418	-0.088	3.582	.865	80.	8.10.18. 4.	0

Table 1. Continued.

LOCATION (NO.)	(NAME)	LATITUDE (DEG.)	LONGITUDE (DEG.)	HEIGHT (M)	GRAVITY OBSERVE 979000.	GRAVITY NORMAL 979000.	GRAVITY ANOMALY OB-NOR	GRAVITY ANOMALY FREE-AIR	GRAVITY ANOMALY BOUGUER	CORRECTIONS FREE-AIR	CORRECTIONS BOUGUER	CORRECTIONS EARTH TIDE	CORRECTIONS TERRAIN	CORRECTIONS ATMOS	DATE Y	DATE M D H M	* FRC (*10)
41	K-06	36.0867	136.3500	48.40	826.294	825.793	0.501	16.303	14.302	14.936	-5.418	-0.089	3.418	.865	80.	8.10.18.12.	0
42	K-07 (BM5252)	36.0868	136.3442	54.90	826.456	825.802	0.654	18.461	15.286	16.942	-6.146	-0.090	2.971	.865	80.	8.10.18.22.	0
43	K-08 (BM5253)	36.0890	136.3393	49.30	828.683	825.991	2.692	18.771	15.794	15.214	-5.519	-0.090	2.542	.865	80.	8.10.18.33.	0
44	K-09	36.0918	136.3338	45.80	830.881	826.232	4.649	19.648	16.692	14.134	-5.127	-0.090	2.171	.866	80.	8.10.18.44.	0
45	K-10	36.0957	136.3262	42.90	832.813	826.568	6.245	20.350	17.442	13.239	-4.803	-0.086	1.895	.866	80.	8.10.19.11.	0
46	FKGS	36.0525	136.2253	9.71	838.162	822.851	15.311	19.177	18.529	2.997	-1.087	0.071	0.439	.869	80.	8.11. 9.39.	0
47	K-10	36.0957	136.3262	42.90	832.803	826.568	6.235	20.340	17.432	13.239	-4.803	0.141	1.895	.866	80.	8.11.11.39.	0
48	K-11 (NARUKA BR.)	36.1008	136.3308	46.20	831.814	827.007	4.807	19.930	17.629	14.257	-5.172	0.143	2.871	.866	80.	8.11.12.24.	0
49	K-12	36.1037	136.3262	39.00	835.395	827.256	8.139	21.040	19.327	12.035	-4.366	0.142	2.653	.866	80.	8.11.12.35.	0
50	K-13	36.1043	136.3175	32.80	837.072	827.308	9.764	20.753	19.021	10.122	-3.672	0.140	1.940	.867	80.	8.11.12.44.	0
51	K-14	36.1067	136.3120	27.60	838.913	827.515	11.398	20.783	19.394	8.517	-3.090	0.138	1.701	.867	80.	8.11.12.51.	0
52	K-15	36.1068	136.3085	26.00	840.303	827.523	12.780	21.671	20.271	8.024	-2.911	0.131	1.511	.867	80.	8.11.13. 9.	0
53	K-16	36.1077	136.3040	26.30	841.384	827.600	13.784	22.767	21.139	8.116	-2.944	0.127	1.316	.867	80.	8.11.13.19.	0
54	K-17	36.1082	136.3000	24.30	840.997	827.644	13.353	21.720	20.186	7.499	-2.720	0.120	1.186	.868	80.	8.11.13.32.	0
55	K-18	36.1090	136.2947	22.00	840.913	827.712	13.201	20.858	19.443	6.789	-2.463	0.116	1.048	.868	80.	8.11.13.40.	0
56	K-19	36.1110	136.2892	20.90	841.309	827.885	13.424	20.742	19.335	6.450	-2.340	0.110	0.933	.868	80.	8.11.13.49.	0
57	K-20	36.1177	136.2878	20.50	842.406	828.461	13.945	21.139	19.790	6.326	-2.295	0.102	0.946	.868	80.	8.11.14. 0.	0
58	K-21	36.1182	136.2833	18.70	842.080	828.504	13.576	20.215	18.977	5.771	-2.093	0.095	0.856	.868	80.	8.11.14.11.	0
59	K-22	36.1197	136.2778	16.50	842.702	828.633	14.069	20.029	18.951	5.092	-1.847	0.081	0.769	.868	80.	8.11.14.28.	0
60	K-23	36.1185	136.2727	15.60	843.141	828.530	14.611	20.294	19.245	4.814	-1.746	0.073	0.698	.868	80.	8.11.14.38.	0

Table 1. Continued.

LOCATION (NO.)	(NAME)	LATITUDE (DEG.)	LONGITUDE (DEG.)	HEIGHT (M)	GRAVITY OBSERVE 979000.	GRAVITY NORMAL 979000.	GRAVITY ANOMALY OB-NOR	GRAVITY ANOMALY FREE-AIR	GRAVITY ANOMALY BOUGUER	CORRECTIONS FREE-AIR	CORRECTIONS BOUGUER	CORRECTIONS EARTH TIDE	CORRECTIONS TERRAIN	CORRECTIONS ATMOS	DATE Y	DATE M D H M	* FRC (*10)
61	K-24	36.1172	136.2690	13.90	843.664	828.418	15.246	20.404	19.501	4.290	-1.556	0.066	0.653	.869	80.	8.11.14.46.	0
62	K-25	36.1148	136.2635	13.50	844.318	828.212	16.106	21.141	20.225	4.166	-1.511	0.058	0.595	.869	80.	8.11.14.56.	0
63	K-26	36.1130	136.2580	11.80	844.370	828.057	16.313	20.824	20.052	3.641	-1.321	0.011	0.549	.869	80.	8.11.15.48.	0
64	K-27	36.1137	136.2510	10.00	844.106	828.117	15.989	19.944	19.326	3.086	-1.120	0.003	0.502	.869	80.	8.11.15.57.	0
65	K-28	36.1152	136.2465	10.30	843.438	828.246	15.192	19.239	18.557	3.179	-1.153	-0.004	0.471	.869	80.	8.11.16. 5.	0
66	K-29	36.1132	136.2412	9.10	843.157	828.074	15.083	18.761	18.190	2.808	-1.019	-0.017	0.448	.869	80.	8.11.16.20.	0
67	K-30	36.1120	136.2367	8.80	842.654	827.970	14.684	18.268	17.708	2.716	-0.985	-0.022	0.425	.869	80.	8.11.16.27.	0
68	K-31	36.1110	136.2335	8.50	842.469	827.885	14.584	18.077	17.537	2.623	-0.952	-0.026	0.412	.869	80.	8.11.16.32.	0
69	K-32 (BM008-404)	36.1105	136.2318	8.30	842.374	827.842	14.532	17.963	17.441	2.561	-0.929	-0.031	0.407	.869	80.	8.11.16.38.	0
70	K-33 (BM900)	36.1085	136.2308	8.40	842.123	827.669	14.454	17.915	17.379	2.592	-0.940	-0.038	0.404	.869	80.	8.11.16.47.	0
71	K-34	36.1120	136.2223	7.00	841.925	827.970	13.955	16.984	16.576	2.160	-0.784	-0.052	0.376	.869	80.	8.11.17. 8.	0
72	K-35	36.1148	136.2183	6.10	841.874	828.212	13.662	16.414	16.095	1.882	-0.683	-0.060	0.364	.869	80.	8.11.17.21.	0
73	K-36	36.1153	136.2130	6.50	841.525	828.255	13.270	16.146	15.769	2.006	-0.728	-0.064	0.351	.869	80.	8.11.17.29.	0
74	K-37	36.1137	136.2092	5.90	841.119	828.117	13.002	15.692	15.383	1.821	-0.661	-0.070	0.351	.869	80.	8.11.17.40.	0
75	K-38	36.1133	136.2053	5.80	840.773	828.082	12.691	15.350	15.049	1.790	-0.649	-0.074	0.348	.869	80.	8.11.17.49.	0
76	K-39	36.1145	136.2003	5.30	840.500	828.186	12.314	14.819	14.573	1.636	-0.593	-0.077	0.347	.869	80.	8.11.17.57.	0
77	K-40	36.1152	136.1967	4.50	840.526	828.246	12.280	14.538	14.386	1.389	-0.504	-0.080	0.352	.870	80.	8.11.18. 4.	0
78	K-41	36.1158	136.1912	4.30	840.968	828.298	12.670	14.867	14.750	1.327	-0.481	-0.082	0.364	.870	80.	8.11.18.11.	0
79	K-42	36.1165	136.1863	4.30	841.871	828.358	13.513	15.710	15.612	1.327	-0.481	-0.084	0.384	.870	80.	8.11.18.19.	0
80	K-43	36.1182	136.1808	4.90	843.362	828.504	14.858	17.239	17.118	1.512	-0.549	-0.086	0.427	.870	80.	8.11.18.27.	0

Table 1. Continued.

LOCATION (NO.)	LOCATION (NAME)	LATITUDE (DEG.)	LONGITUDE (DEG.)	HEIGHT (M)	----GRAVITY--- OBSERVE	----GRAVITY--- NORMAL	---GRAVITY ANOMALY----- OB-NOR	---GRAVITY ANOMALY----- FREE-AIR	---GRAVITY ANOMALY----- BOUGUER	------------CORRECTIONS------------ FREE-AIR	CORRECTIONS BOUGUER	CORRECTIONS EARTH TIDE	CORRECTIONS TERRAIN	CORRECTIONS ATMOS	DATE Y	DATE M D H M	* FRC (*10)
					979000.	979000.											
81	K-44	36.1195	136.1772	5.60	844.016	828.616	15.400	17.998	17.847	1.728	-0.627	-0.087	0.476	.869	80.	8.11.18.35.	0
82	K-44	36.1222	136.1692	7.00	846.741	828.849	17.892	20.922	20.958	2.160	-0.784	0.130	0.820	.869	80.	8.12.12.23.	0
83	K-45	36.1322	136.1613	5.10	847.784	829.710	18.074	20.518	20.410	1.574	-0.571	0.131	0.463	.870	80.	8.12.12.32.	0
84	K-46	36.1372	136.1552	4.70	848.562	830.140	18.422	20.742	20.629	1.450	-0.526	0.131	0.413	.870	80.	8.12.12.42.	0
85	K-47	36.1362	136.1443	8.10	848.780	830.054	18.726	22.095	21.651	2.500	-0.907	0.130	0.463	.869	80.	8.12.12.52.	0
86	K-48	36.1383	136.1298	11.90	847.574	830.235	17.339	21.881	21.090	3.672	-1.332	0.129	0.542	.869	80.	8.12.13. 4.	0
87	K-50	36.1368	136.1175	8.40	849.489	830.105	19.384	22.845	23.285	2.592	-0.940	0.127	1.380	.869	80.	8.12.13.15.	0
88	K-51	36.1413	136.1095	38.70	842.627	830.493	12.134	24.943	21.081	11.943	-4.332	0.124	0.470	.866	80.	8.12.13.25.	0
89	K-52	36.1430	136.0977	7.60	848.059	830.639	17.420	20.634	20.260	2.345	-0.851	0.120	0.476	.869	80.	8.12.13.37.	0
90	K-53 (OHMICHI BR.)	36.1393	136.0895	6.30	850.004	830.321	19.683	22.497	22.337	1.944	-0.705	0.116	0.545	.869	80.	8.12.13.47.	0
91	E-01 (BM5254)	36.0935	136.3082	43.10	835.050	826.379	8.671	22.838	19.412	13.301	-4.825	0.051	1.399	.866	80.	8.12.15.23.	0
92	E-02	36.0790	136.3202	67.80	825.110	825.131	-0.021	21.766	16.403	20.923	-7.590	0.038	2.228	.863	80.	8.12.15.39.	0
93	E-03	36.0650	136.3325	106.00	815.416	823.926	-8.510	25.061	16.419	32.712	-11.867	0.031	3.225	.860	80.	8.12.15.47.	0
94	E-04	36.0578	136.3503	150.00	802.476	823.307	-20.831	26.315	14.843	46.290	-16.793	0.023	5.321	.856	80.	8.12.15.57.	0
95	E-05 (EIHEIJI)	36.0520	136.3573	186.00	792.874	822.808	-29.934	28.318	13.654	57.400	-20.823	0.015	6.159	.852	80.	8.12.16. 6.	0
96	E-06 (USAKA TUNNEL)	36.0473	136.3477	276.30	777.742	822.404	-44.662	41.448	13.101	85.266	-30.932	0.002	2.585	.843	80.	8.12.16.21.	0
97	E-07	36.0352	136.3350	119.00	805.683	821.363	-15.680	21.902	16.180	36.723	-13.322	-0.009	7.600	.859	80.	8.12.16.34.	0
98	E-08 (TSURUMI BR.)	35.9817	136.3665	104.90	799.547	816.764	-17.217	16.015	9.450	32.372	-11.744	-0.025	5.178	.860	80.	8.12.16.55.	0
99	E-09	35.9722	136.3742	112.80	794.225	815.947	-21.722	13.947	8.396	34.810	-12.628	-0.031	7.077	.859	80.	8.12.17. 3.	0
100	E-10	35.9597	136.3703	123.70	789.003	814.873	-25.870	13.162	6.162	38.174	-13.848	-0.039	6.848	.858	80.	8.12.17.14.	0

Table 1. Continued.

LOCATION (NO.)	(NAME)	LATITUDE (DEG.)	LONGITUDE (DEG.)	HEIGHT (M)	GRAVITY OBSERVE (979000.)	GRAVITY NORMAL (979000.)	GRAVITY ANOMALY OB-NOR	GRAVITY ANOMALY FREE-AIR	GRAVITY ANOMALY BOUGUER	CORRECTIONS FREE-AIR	CORRECTIONS BOUGUER	CORRECTIONS EARTH TIDE	CORRECTIONS TERRAIN	CORRECTIONS ATMOS	DATE Y	DATE M D H M	* FRC (*10)
101	E-11	35.9485	136.3602	137.70	785.875	813.911	-28.036	15.315	5.186	42.494	-15.416	-0.044	5.286	.857	80.	8.12.17.22.	0
102	E-12	35.9418	136.3518	199.50	771.770	813.335	-41.565	20.851	4.262	61.566	-22.334	-0.053	5.745	.851	80.	8.12.17.36.	0
103	E-13	35.9402	136.3628	155.50	781.296	813.198	-31.902	16.940	3.467	47.987	-17.408	-0.067	3.935	.855	80.	8.12.18. 2.	0
104	E-14 (SHIRAWA BR.)	35.9305	136.3662	162.30	777.020	812.364	-35.344	15.596	3.550	50.086	-18.170	-0.070	6.124	.854	80.	8.12.18. 9.	0
105	E-15	35.9168	136.3547	195.90	768.830	811.188	-42.358	18.948	2.116	60.455	-21.931	-0.074	5.099	.851	80.	8.12.18.19.	0
106	E-16	35.9128	136.3327	243.00	761.197	810.845	-49.648	26.189	4.440	74.990	-27.204	-0.078	5.455	.847	80.	8.12.18.30.	0
107	E-17	35.9330	136.3038	78.00	799.995	812.579	-12.584	12.349	8.144	24.071	-8.732	-0.082	4.527	.862	80.	8.12.18.48.	0
108	E-18	35.9327	136.2865	52.30	807.896	812.554	-4.658	12.347	10.689	16.140	-5.855	-0.084	4.197	.865	80.	8.12.18.56.	0
109	E-19	35.9313	136.2673	32.20	815.934	812.433	3.501	14.304	12.718	9.937	-3.605	0.028	2.018	.867	80.	8.13.10. 8.	0
110	E-20 (II BM3267)	35.9327	136.2503	21.70	819.590	812.554	7.036	14.601	13.404	6.697	-2.429	0.045	1.233	.868	80.	8.13.10.30.	0
111	E-21	35.9433	136.2323	15.10	822.445	813.464	8.981	14.509	15.018	4.660	-1.690	0.059	2.199	.869	80.	8.13.10.49.	0
112	S-07	35.9453	136.1680	18.30	817.195	813.636	3.559	10.075	8.479	5.647	-2.049	0.074	0.453	.868	80.	8.13.11.12.	0
113	S-08	35.9450	136.1412	19.50	817.036	813.610	3.426	10.312	8.955	6.018	-2.183	0.083	0.826	.868	80.	8.13.11.27.	0
114	S-09	35.9695	136.1408	12.40	824.186	815.715	8.471	13.166	12.239	3.827	-1.388	0.094	0.461	.869	80.	8.13.11.48.	0
115	S-10	35.9700	136.1617	13.00	823.239	815.758	7.481	12.361	11.323	4.012	-1.455	0.109	0.417	.869	80.	8.13.12.28.	0

Table 1. Continued.

LOCATION (NO.)	(NAME)	LATITUDE (DEG.)	LONGITUDE (DEG.)	HEIGHT (M)	----GRAVITY--- OBSERVE	NORMAL	---GRAVITY ANOMALY----- OB-NOR	FREE-AIR	BOUGUER	------------CORRECTIONS------------ FREE-AIR	BOUGUER	EARTH TIDE	TERRAIN	ATMOS	Y	DATE M D H M	* FRC (*10)
					979000.	979000.											
10KUFS166		36.5649	136.6613	33.79	857.990	867.053	-9.063	2.231	-1.060	10.428	-3.783	-0.035	0.491	.867	82.	7.12. 9.15.	A0 2
180MARU	F 0	36.1334	136.2695	11.50	846.544	829.810	16.735	21.152	20.553	3.549	-1.287	-0.013	0.688	.869	82.	7.12.10.44.	C1 0
181	F 1	36.1473	136.2547	8.80	849.326	831.006	18.320	21.905	21.452	2.716	-0.985	0.014	0.533	.869	82.	7.12.11.49.	D2 0
182	F 2	36.1472	136.2531	8.80	848.888	830.999	17.889	21.474	21.009	2.716	-0.985	0.019	0.520	.869	82.	7.12.11.58.	C2 0
183	F 3	36.1470	136.2510	8.70	848.797	830.989	17.808	21.362	20.887	2.685	-0.974	0.023	0.499	.869	82.	7.12.12. 8.	D2 0
184	F 4	36.1470	136.2500	8.70	848.586	830.989	17.598	21.152	20.669	2.685	-0.974	0.027	0.491	.869	82.	7.12.12.17.	D2 0
185	F 5	36.1537	136.2487	7.90	848.238	831.565	16.673	19.981	19.577	2.438	-0.884	0.034	0.481	.869	82.	7.12.12.31.	D2 0
186	F 6	36.1524	136.2470	7.60	847.492	831.449	16.043	19.257	18.877	2.345	-0.851	0.067	0.470	.869	82.	7.12.13.56.	D2 0
187	F 7	36.1524	136.2460	7.60	847.189	831.448	15.741	18.956	18.564	2.345	-0.851	0.069	0.459	.869	82.	7.12.14. 4.	D2 0
188	F 8	36.1524	136.2449	7.70	846.879	831.449	15.429	18.675	18.265	2.376	-0.862	0.071	0.452	.869	82.	7.12.14. 9.	D2 0
189	F 9	36.1524	136.2441	7.70	846.776	831.448	15.328	18.574	18.159	2.376	-0.862	0.072	0.447	.869	82.	7.12.14.14.	D2 0
190	F10	36.1524	136.2434	7.70	846.646	831.450	15.196	18.442	18.022	2.376	-0.862	0.073	0.442	.869	82.	7.12.14.18.	D2 0
191	F11	36.1524	136.2427	7.70	846.529	831.451	15.078	18.324	17.900	2.376	-0.862	0.075	0.438	.869	82.	7.12.14.28.	D2 0
192	F12	36.1528	136.2421	8.20	846.234	831.480	14.754	18.154	17.670	2.531	-0.918	0.077	0.434	.869	82.	7.12.14.38.	C2 0
193	F13	36.1523	136.2412	7.00	846.413	831.443	14.970	17.999	17.647	2.160	-0.784	0.078	0.431	.869	82.	7.12.14.45.	C2 0
194	F14	36.1523	136.2406	7.00	846.341	831.445	14.897	17.926	17.570	2.160	-0.784	0.079	0.428	.869	82.	7.12.14.52.	D2 0
195	F15	36.1523	136.2399	6.70	846.377	831.442	14.935	17.872	17.542	2.068	-0.750	0.079	0.420	.869	82.	7.12.15. 0.	D2 0
196	F16	36.1523	136.2393	6.70	846.296	831.445	14.852	17.789	17.456	2.068	-0.750	0.080	0.417	.869	82.	7.12.15. 7.	D2 0
197	F17	36.1523	136.2369	6.70	846.047	831.443	14.604	17.541	17.195	2.068	-0.750	0.080	0.404	.869	82.	7.12.15.17.	C2 0
198	F18	36.1541	136.2472	7.60	847.970	831.593	16.378	19.592	19.212	2.345	-0.851	0.079	0.471	.869	82.	7.12.15.48.	D2 0
199	F19	36.1541	136.2449	7.60	847.237	831.593	15.643	18.858	18.458	2.345	-0.851	0.078	0.451	.869	82.	7.12.15.54.	D2 0

Table 1. Continued.

LOCATION (NO.)	(NAME)	LATITUDE (DEG.)	LONGITUDE (DEG.)	HEIGHT (M)	GRAVITY OBSERVE 979000.	GRAVITY NORMAL 979000.	GRAVITY ANOMALY OB-NOR	GRAVITY ANOMALY FREE-AIR	GRAVITY ANOMALY BOUGUER	CORRECTIONS FREE-AIR	CORRECTIONS BOUGUER	CORRECTIONS EARTH TIDE	CORRECTIONS TERRAIN	CORRECTIONS ATMOS	DATE 'Y M D H M	*	FRC (*10)
200	F20	36.1541	136.2460	7.60	847.606	831.593	16.012	19.227	18.834	2.345	-0.851	0.075	0.458	.869	82. 7.12.16.15.	D2	0
201	F21	36.1516	136.2338	5.40	845.895	831.378	14.517	17.053	16.838	1.666	-0.605	0.071	0.389	.869	82. 7.12.16.31.	C2	0
202	F22	36.1522	136.2302	5.30	845.724	831.432	14.293	16.798	16.576	1.636	-0.593	0.068	0.373	.869	82. 7.12.16.42.	D2	0
203	F23	36.1523	136.2264	5.50	845.076	831.443	13.633	16.200	15.937	1.697	-0.616	0.066	0.353	.869	82. 7.12.16.49.	D2	0
204	F24	36.1528	136.2237	5.10	847.971	831.482	16.489	18.932	18.705	1.574	-0.571	0.063	0.344	.870	82. 7.12.16.58.	D2	2
205	F25	36.1525	136.2199	4.70	844.264	831.455	12.809	15.129	14.932	1.450	-0.526	0.059	0.329	.870	82. 7.12.17. 8.	D2	0
206	F26	36.1526	136.2157	4.50	843.855	831.469	12.387	14.645	14.457	1.389	-0.504	0.056	0.316	.870	82. 7.12.17.16.	D2	0
207	F27	36.1530	136.2099	4.60	843.599	831.505	12.093	14.382	14.166	1.420	-0.515	0.051	0.298	.870	82. 7.12.17.28.	D2	0
208	F28	36.1473	136.2560	8.80	849.610	831.011	18.598	22.183	21.743	2.716	-0.985	0.042	0.545	.869	82. 7.12.17.48.	D2	0
209	F29	36.1465	136.2587	7.60	849.048	830.937	18.111	21.326	21.048	2.345	-0.851	0.037	0.573	.869	82. 7.12.17.58.	D2	0
210	F30	36.1479	136.2588	7.70	849.042	831.064	17.978	21.223	20.935	2.376	-0.862	0.032	0.574	.869	82. 7.12.18. 7.	C2	0
211	F31	36.1491	136.2610	7.80	849.674	831.168	18.505	21.782	21.511	2.407	-0.873	0.027	0.602	.869	82. 7.12.18.17.	C2	0
212	F32	36.1496	136.2632	8.40	850.395	831.211	19.184	22.645	22.331	2.592	-0.940	0.022	0.626	.869	82. 7.12.18.26.	C2	0
213	F33	36.1494	136.2665	8.40	850.293	831.189	19.104	22.565	22.299	2.592	-0.940	0.017	0.674	.869	82. 7.12.18.35.	C2	0
214	F34	36.1495	136.2713	8.50	850.246	831.197	19.048	22.541	22.337	2.623	-0.952	0.013	0.748	.869	82. 7.12.18.43.	C2	0
215	F35	36.1495	136.2754	8.80	850.206	831.200	19.006	22.590	22.439	2.716	-0.985	0.009	0.834	.869	82. 7.12.18.50.	C2	0
216	F36	36.1484	136.2806	10.30	850.389	831.108	19.281	23.329	23.143	3.179	-1.153	0.004	0.968	.869	82. 7.12.19. 0.	D2	0
217	F37	36.1487	136.2825	14.10	849.871	831.127	18.743	23.963	23.396	4.351	-1.578	-0.001	1.011	.869	82. 7.12.19. 8.	C2	0
218	F38	36.1491	136.2866	25.90	847.107	831.162	15.946	24.806	23.041	7.993	-2.900	-0.004	1.135	.868	82. 7.12.19.14.	C2	0
180	F39	36.1334	136.2695	11.50	846.569	829.810	16.759	21.177	20.577	3.549	-1.287	-0.012	0.688	.869	82. 7.12.19.29.	C1	0
10	KUFS166	36.5649	136.6613	33.79	857.990	867.053	-9.063	2.231	-1.060	10.428	-3.783	-0.067	0.491	.867	82. 7.12.21.42.	A0	0

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