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HAILE SELASSIE 1st UNIVERSITY
[UNI]VERSITY COLLEGE ADDIS ABABA
FACULTY OF SCIENCE

BULLETIN of the GEOPHYSICAL OBSERVATORY

MARCH 1962 NUMBER 1

MESURES DE L'INDICE "K" A ADDIS ABABA

JANVIER 1958 A JUIN 1961

PIERRE-NOEL MAYAUD

__Abstract__:

The magnetic K indices for the period of January 1958 to June 1961 are the first in the series of the K indices for Addis Ababa. The base chosen for the lower limit of K=9 is 300 gammas. This value of 300 gammas may seem too low for an equatorial station; on the other hand it has the advantage of differentiating the periods of lower magnetic activity. A comparison with indices calculated from a higher base remains possible.

Les mesures d'indices K pour la période 1958-1961 forment le début de la série d'Addis Ababa. La base choisie (lower limit for K=9) est de 300 gammas. Cette base a l'avantage de mieux distinguer la variation de l'agitation magnétique en période calme. Une comparaison d'indices à indices avec Huancayo, de situation semblable sous l'électrojet et où la base est de 600 gammas, reste possible; elle supposerait seulement que l'on retranche une unité aux indices 1 à 8 d'Addis Ababa (ceci étant basé sur le fait de la croissance logarithmique de l'échelle de mesure des K, croissance qui est en gros basée sur un facteur 2); une incertitude subsisterait seulement pour les indices 0 et 9.

Il est inutile de souligner que l'élimination du Sq + L n'est pas toujours aisée en une telle station. Cependant, étant donnée l'amplitude de cette variation régulière, elle présente peut-être moins de difficulté qu'en d'autres stations; nous pensons en particulier à celles de latitude tropicale.

La difficulté principale réside plutôt dans l'estimation du L, qui apparait souvent très clairement, mais parfois semble absent le jour suivant. Autrement dit, il existe sur le L la même variabilité jour à jour que sur le Sq.

Dans ces mesures, seule la composante horizontale a été considérée, parce que c'est elle qui comporte toujours les plus grandes variations.

Les mesures ont été faites en dessinant au crayon sur chaque enregistrement ce qui semblait être le Sq + L du jour. Il est évident que certains de ces tracés effectués sur trois années et demie d'enregistrements pourraient prêter à discussion. Cependant l'expérience acquise peu à peu a conduit à revenir sur des tracés déjà faits pour les modifier; et s'il a subsisté des cas douteux, le fait que l'entreprise ait été menée à son terme manifeste qu'une réelle cohérence existe dans l'ensemble de ces tracés: nous voulons dire par là qu'il serait possible d'énoncer des règles, en général applicables, sur les différentes formes que peut prendre en une telle station le Sq + L.

De telles règles jouent l'objet d'une communication ultérieure, premier élément peut-être de ce qui constituera l'Atlas pour la mesure de l'indice K dont la rédaction a été décidée par le comité 9 du I.A.G.A. lors du Congrès de Helsinki.

K 1958

Janvier 1958

43210	11104	323--	12231	53202	102311
64324	11201	345--	43331	5433-	511233
55234	45333	355--	5564-	5452-	434354
74244	45343	6-3-3	4574-	5454-	424552
34142	33222	3---3	3333-	3543-	103232
30002	10012	2---2	2211-	2231-	102221
32012	20042	33--2	33442	33314	322412
31122	31032	44--3	43226	22312	342203

Février 1958

30043	22233	84211	13243	24321	131
33225	53312	86231	03334	53312	313
43336	64541	97441	35562	54533	415
35347	55643	96323	37654	45533	425
22346	55432	83322	34-34	23322	325
00043	43414	55043	44232	33200	122
11254	34243	64322	34444	44222	142
21245	34224	53132	32344	53320	131

Mars 1958

22152	42433	35323	31355	32324	33-332
01154	45333	25435	32445	32332	32-213
22369	45544	26527	46555	63444	44-364
34548	45355	46626	36545	42345	55-373
03535	32323	35563	25543	41213	51-143
11413	22122	24443	23544	40356	3-3133
10543	43132	53523	25554	41344	4-2243
32533	44222	44331	32555	44243	2-2333

Avril 1958

31312	43121	21124	23333	21023	01232
44433	34120	22135	34444	22034	13555
46544	65124	22436	66564	33233	33556
46464	55113	53266	55663	43322	32545
35253	32112	32241	54321	31113	41432
33122	22010	11132	23431	30211	43333
33243	42331	22134	55333	11111	14443
43353	52241	32232	55434	40310	23442

Mai 1958

32121	22123	00242	31311	---00	323532
43233	32334	21455	44332	-----	443543
54233	34574	44555	44543	3-311	644754
43343	33455	44554	44633	2-212	552743
31111	11354	23244	13411	1--10	532413
22102	11112	12432	33320	0-013	322426
33202	12213	14343	13221	0-103	332416
33234	13323	14534	1431-	--104	343335

Juin 1958

63111	06034	30112	10112	33222	12143
652-3	57225	33416	22132	45444	43364
652-3	67245	65347	52343	65554	34773
552-1	4726v5	44335	52332	86344	23664
332-2	15133	32222	41311	73222	11452
43211	14331	33211	10141	42122	12343
43211	34342	33241	22221	43333	11743
40001	42354	23230	01313	33132	23711

K 1958

Juillet 1958

30311	21154	23211	23412	23122	213221
32451	22244	14342	24545	55224	235333
43354	35864	56442	25665	55335	365243
43455	25973	34243	25545	35346	363343
32232	14840	13101	02424	25134	131212
11231	04831	22321	00312	51043	121115
11232	24721	34111	00431	62033	233432
12234	12(7)43	32422	30443	62043	253232

Août 1958

12201	12122	21221	20321	1516-	142121
23131	32122	43434	42533	2658-	262433
35333	34335	63634	46544	1756-	383442
55313	33226	43523	45553	4536-	475443
53211	14113	23302	25412	32365	241310
21111	21123	10212	45221	221-1	321011
21011	22123	32111	26220	122-2	243120
22001	21123	22132	16211	313-1	243220

Septembre 1958

00146	21431	32010	24001	10133	31300
01146	33333	21130	55113	11205	32220
23668	24353	43222	64233	31437	64533
42756	24453	43133	74232	32336	54436
21673	21332	11112	43121	21125	23213
00573	10321	11001	31101	12014	01102
00564	04131	10112	51221	21126	22113
01673	14543	20112	31212	11226	23113

Octobre 1958

12013	22111	11013	22202	21221	131313
52424	34411	10233	32321	46433	432434
74635	24321	41425	44543	37475	537553
33324	44322	42433	33342	38573	437444
10323	33100	11132	22131	13461	216224
11203	13001	12123	13222	23260	155335
30412	33012	32213	22132	25551	465432
44123	33211	31222	23323	15450	254442

Novembre 1958

21201	02-01	41210	21020	12102	212--
21432	01-23	42401	64221	12312	235--
33323	24424	32314	44432	33333	33652
4432-	24437	53314	42222	33443	33653
31(3)--	12014	33123	12221	01333	22522
452-1	02004	02211	22122	20213	333-1
35221	1-124	13101	21302	10124	333-1
32220	3-112	12021	22100	21135	233-0

Décembre 1958

12346	11041	12441	31532	11221	413212
22353	23230	1145-	62442	32210	343313
24366	44173	42443	53434	53631	244234
16395	43231	53545	54555	44531	344242
23264	21231	32753	52423	13211	343242
13243	30331	22533	26023	11421	433241
13262	31420	22533	35232	32322	423333
15262	31311	42443	15223	13224	332321

K 1959

Janvier 1959

00113	23-34	34101	21311	01311	202213
01521	32-24	20212	14320	04231	442332
21433	44434	32454	45442	16342	533444
13233	43344	23344	65443	23535	663554
02133	31212	24110	23211	22416	842231
01123	22463	13210	43211	11026	322331
02233	54455	34321	43232	22205	313542
01025	4-555	44231	32321	12203	323412

Février 1959

11222	21132	03323	45010	03304	424
34354	11130	33336	-4233	13315	524
35355	43343	54347	65144	34528	743
35545	53322	95456	52245	35528	645
34443	41422	53254	51032	13515	545
23424	32223	42444	61111	13016	454
13444	43322	32344	52131	32025	436
14453	31423	44431	50110	23024	435

Mars 1959

33231	20400	13111	2221-	11322	153621
34322	10100	14231	1312-	12334	343441
56444	31324	35544	34134	33636	786644
66353	24233	36444	231-3	43443	966545
44332	11221	34423	121-2	12334	785412
52422	00211	13331	112-1	01023	455512
55345	21200	23120	101-1	10424	465524
33422	03201	11231	224-0	13224	566125

Avril 1959

20321	12155	22243	10111	21042	31011
21111	12255	43442	22123	31154	32153
53641	32478	33564	55243	51175	54454
23523	33559	55343	44324	32674	52453
21112	13428	43332	22122	31542	32253
11031	21124	31211	20110	12332	22144
02011	34354	40112	22100	00623	11344
12212	32433	52121	12020	00643	44533

Mai 1959

11233	11232	1-111	32321	12235	300022
31125	31535	4-311	53443	33266	232114
32155	23737	65413	65544	45575	142124
33165	34656	-6426	65444	34475	422235
33225	33522	-5315	33232	12153	211142
11111	11433	-7214	12311	13041	311131
12141	00233	-4304	12323	32332	311023
22451	13332	-4404	31421	42262	211214

Juin 1959

21433	22234	00011	10122	11243	303-4
33434	33334	42134	30434	33443	413-3
55564	54554	42135	41453	34423	55476
45363	53553	71125	30444	35314	44-7-
13223	32233	42231	12323	23301	35-6-
13232	11213	32121	12211	13221	24-3-
13041	31222	12110	22122	23331	05-3-
14342	31322	10120	03222	23333	04-4-

Juillet 1959

-310-	12103	35112	53631	32233	421121
-411-	34344	43233	53634	34234	444323
34425	44555	53368	64754	45455	554314
13235	45364	33358	34754	43466	454335
01133	23321	23228	23323	42243	333114
011-1	13230	62119	17733	32023	321012
101-3	22321	41118	48223	31144	441023
201-1	31222	41228	47434	34144	442112

Août 1959

32311	13133	22123	45133	42242	220321
54432	(4)4325	32324	56436	54543	311332
55533	-5465	34443	(8)7757	66664	332343
44552	53453	43336	(8)6646	65644	431233
4233(3)	51322	31213	73324	22413	120221
31222	13242	10112	56323	34321	100323
34222	44133	11323	43445	44311	200233
21131	33342	22124	53325	34423	112112

Septembre 1959

33354	31101	13333	22443	35133	32311
23364	30302	33243	42344	55334	33323
56575	43543	54365	34556	76555	56445
55574	43443	54344	36656	66235	55363
43453	32212	43143	23356	55244	22223
22142	22402	12123	23225	52532	24303
43434	12311	13123	44326	55533	43313
34755	01323	11533	34434	43524	43233

Octobre 1959

31132	41021	11021	11322	03301	111053
45342	33310	11134	23433	26115	431143
56554	63333	10245	15644	15335	553355
55343	64321	01454	17734	24345	543255
23242	22011	02241	033-1	22123	521142
32334	41113	01122	13310	34023	430134
42426	52133	02034	23431	23122	321155
51624	44110	31143	24340	33023	410456

Novembre 1959

33303	20102	22131	01021	02311	13511
45433	32232	20332	15341	34423	33833
57455	33324	22353	23451	45613	55936
54545	41334	32352	33341	44413	53856
45333	31123	11231	22230	23212	41525
35533	42320	02241	20420	22301	22416
45554	44452	03240	21511	34611	33443
34432	43144	23331	32221	24214	45324

Décembre 1959

31030	22011	00341	10222	00211	232200
44350	63112	33243	21320	11333	355342
55446	62253	45466	42442	31654	455453
55545	51152	35366	42432	22353	375544
23425	31031	22252	21321	11241	345131
44525	20321	12354	32233	03612	344221
23527	41313	12444	22233	13522	344233
14423	32321	24434	32102	12331	442222

K 1960

Janvier 1960

00112	30002	12045	12331	52111	120310
20123	33123	32134	01425	43453	220303
12345	35137	54276	23635	65553	443602
11244	33238	44275	13525	55353	333433
01243	12015	42054	15424	33331	222402
01222	22104	43152	14333	43322	101102
02213	22205	33562	02323	52321	213200
01223	11125	24352	32223	32321	221101

Février 1960

01121	22121	13130	23312	21000	0222
21341	23314	12141	23534	43230	0332
42455	54524	33533	36755	34422	1532
45446	42534	44543	64543	53312	4536
33333	21323	12233	65322	22200	2423
21424	41221	30132	53332	42301	2422
15443	30331	31653	34351	32003	3304
13333	32210	40422	33233	21013	2423

Mars 1960

24210	20011	22112	52110	00111	110311
23322	43233	31211	62421	32132	122422
55534	52455	43243	74543	33344	435755
44533	42565	63242	54353	32254	436447
22433	11243	42234	33121	22132	225147
23343	21213	41133	33111	21040	104128
34244	21214	41314	53110	11142	114146
34344	10332	21224	52311	02233	113457

Avril 1960

65633	11233	44233	-3310	01055	22545
84656	42445	35555	-3421	01344	21445
96757	53556	45554	35532	14456	44665
84655	42444	5435-	34512	24445	52566
75444	23225	4332-	42211	11355	22339
72323	53314	3311-	24110	01225	22229
73434	35216	2322-	32100	01544	25637
74342	24216	3433-	23100	10543	45347

Mai 1960

71112	35131	21220	14010	001-3	-3-631
73312	45562	54533	23322	212-4	-3-443
73324	56664	76343	46341	31376	54-755
55333	67873	64435	35342	21453	533654
32121	36633	24123	54111	23323	120534
31111	44722	13121	63100	02413	3-0313
22123	63512	21311	61111	11443	2-5512
41134	54614	43321	50011	01-42	4-5524

Juin 1960

32053	33241	21131	12221	32312	45415
52064	52531	12132	21142	53343	46664
63365	65653	33445	33332	33344	57874
64355	56552	23254	11443	54243	54754
22134	32212	01133	00312	31222	22223
21232	31212	02211	00123	32234	24325
22244	23222	12222	00211	32244	34355
10343	22412	11121	11221	33234	35264

K 1960

Juillet 1960

32133	20102	3221-	54102	12321	131344
45345	23212	3334-	53452	33232	332354
55465	43233	453--	44545	43353	343545
54455	42143	443-6	34365	23131	233345
41113	21012	121-5	20244	22130	132353
21021	12002	113-5	22222	31021	111423
42312	11013	312-5	23253	20011	212522
21332	11012	322-5	23245	22121	413424

Août 1960

22110	02012	14113	16322	33110	032542
43131	22434	44332	26324	32211	225552
53333	43564	55335	37546	63332	446674
43222	22554	45423	35654	53231	232652
30100	21322	22210	54223	21121	121522
12110	23313	13141	55152	30211	053522
12000	11323	31231	45133	34121	151421
33100	20412	22131	56163	32110	222423

Septembre 1960

00545	52321	31330	10220	22241	01214
03354	53233	32431	11321	21242	13314
13777	64433	33353	21443	33553	34344
23477	35435	24543	22622	22563	22334
04255	15133	20212	21321	33121	21222
04245	13323	22120	12101	13141	20212
04264	34324	41301	13103	33243	23125
24275	42131	31300	15203	33310	23133

Octobre 1960

33003	57320	30121	11200	10012	313423
43214	75341	51323	23322	10015	434433
54445	77443	56323	33442	21135	645565
54534	77431	32244	23332	21135	545455
53112	65230	10203	11421	11144	543342
35043	76240	11104	10513	11277	445443
43163	76451	22105	12512	22357	554544
53265	74343	24313	11332	31123	432332

Novembre 1960

21142	01000	22743	-2203	03122	1-122
22152	02110	42844	-3334	24234	2-213
33363	33434	65964	54234	75334	-5(2)-3
23453	23333	63964	44255	73223	-3323
12342	11102	56825	52143	33131	-1311
12240	30102	36734	43112	62124	-1222
22351	10102	47755	43021	74233	-4225
33330	10221	3762-	21032	44244	-3035

Décembre 1960

52100	11342	12211	31123	33211	312312
84312	12641	13332	43433	33311	244233
75323	23653	34333	74645	33434	5545-5
75323	34542	24343	33644	34331	456323
43021	32322	12235	10332	42320	333223
43121	12331	22025	11523	32130	364333
64124	64134	14105	12424	43133	364332
43102	34132	24115	23334	33231	232231

K 1961

Janvier 1961

10101	01320	00102	22223	11213	123101
21101	01430	02101	33224	22134	232211
23213	32352	13325	43534	34144	344323
22013	33432	13535	13534	35124	343322
21111	23223	01213	02523	32023	332200
11110	01612	02332	01326	53121	323100
11213	02542	03311	41452	24352	214301
21223	23351	02315	32452	12121	223220

Février 1961

11114	31220	21211	31613	11210	212
02025	32010	42233	51433	33230	022
12126	73222	21534	53534	43342	123
22622	52330	32644	65544	43232	013
10452	41110	00422	36343	33210	033
10342	52110	10421	24525	43101	132
20372	23202	10430	25443	42302	123
11271	34312	10230	25224	33102	101

Mars 1961

22300	50114	12131	31213	21112	123110
11100	43224	11133	22153	34331	334421
33322	42236	43565	55254	35432	434342
23121	52128	42255	64054	44443	534443
10121	31047	21225	22232	12312	323323
11112	21044	21324	12342	22101	152224
32205	13223	31133	11244	10111	143422
21104	03251	11234	01332	10131	311202

Avril 1961

41233	02123	30025	11002	00133	11321
13401	02123	42135	22312	11310	35401
44522	13354	44255	43444	23334	35313
42512	33465	43375	33113	13331	24333
31210	12162	23452	21011	12110	33122
11101	21133	43444	30120	12121	23012
24420	41233	32353	31122	12222	22332
33311	41222	12253	31131	13231	03233

Mai 1961

33003	23111	31320	32023	13223	121013
33004	64331	44221	33124	14525	111323
33215	55453	45441	63334	24436	323235
34223	55433	43451	63134	03313	123225
22112	42123	31201	52022	02313	223133
32124	11221	31201	41122	02313	113123
11144	31322	42211	31023	23214	113122
20042	33323	33101	21140	23121	213132

Juin 1961

21110	11201	01013	41021	46311	00051
3(3)432	24422	24103	13242	55223	23162
45433	36533	23114	21344	75323	14363
45332	25332	13115	21333	55123	23341
54120	25211	1(1)004	21100	54122	21020
44111	44230	01202	10303	24101	10021
32112	43320	10112	22324	44222	10010
30113	33220	00142	22413	65212	00122

GEOMAGNETIC ACTIVITY AT ADDIS ABABA

JANUARY – JUNE 1960

P. GOUIN AND E. CAMBRON

Detailed description of the installation, instrumentation, control, and reduction of the magnetograms has already been given in previous issues of this Bulletin. As a summary:

Location of the Observatory:

Geographic coordinates	:	N 09° 01' 45" E 38° 45' 56"
Geomagnetic coordinates	:	N 5°3 L 109.2
Elevation	:	2442.5 meters

Instruments:

Absolute

- -Quartz Horizontal Magnetometers, no. 377, 378, and 379.
- -Inclinatorium Ruska no. 6393.
- -D-Magnetometer Chasselon no. 65901.

Variographs

- -Standard Ruska Magnetograph, with
  - -Electromagnetic sensitivity control,
  - -Magnetic temperature compensation,
  - -Time base used: 20 mm/hour.

Time control

- -Riefler Type A3 invar pendulum compensated for pressure variations.
  - -Controlled by radio daily.

Magnetic Data

The magnetic data for the period January - June 1960 are presented either in graphical or tabular form and according to the following order:

- -Base-Line and Scale values
- -Mean hourly values and daily range of H
- -Mean hourly values and daily range of D
- -Mean hourly values and daily range of Z
- -Daily mean and extreme values of H
- -Daily mean and extreme values of D
- -Daily mean and extreme values of Z

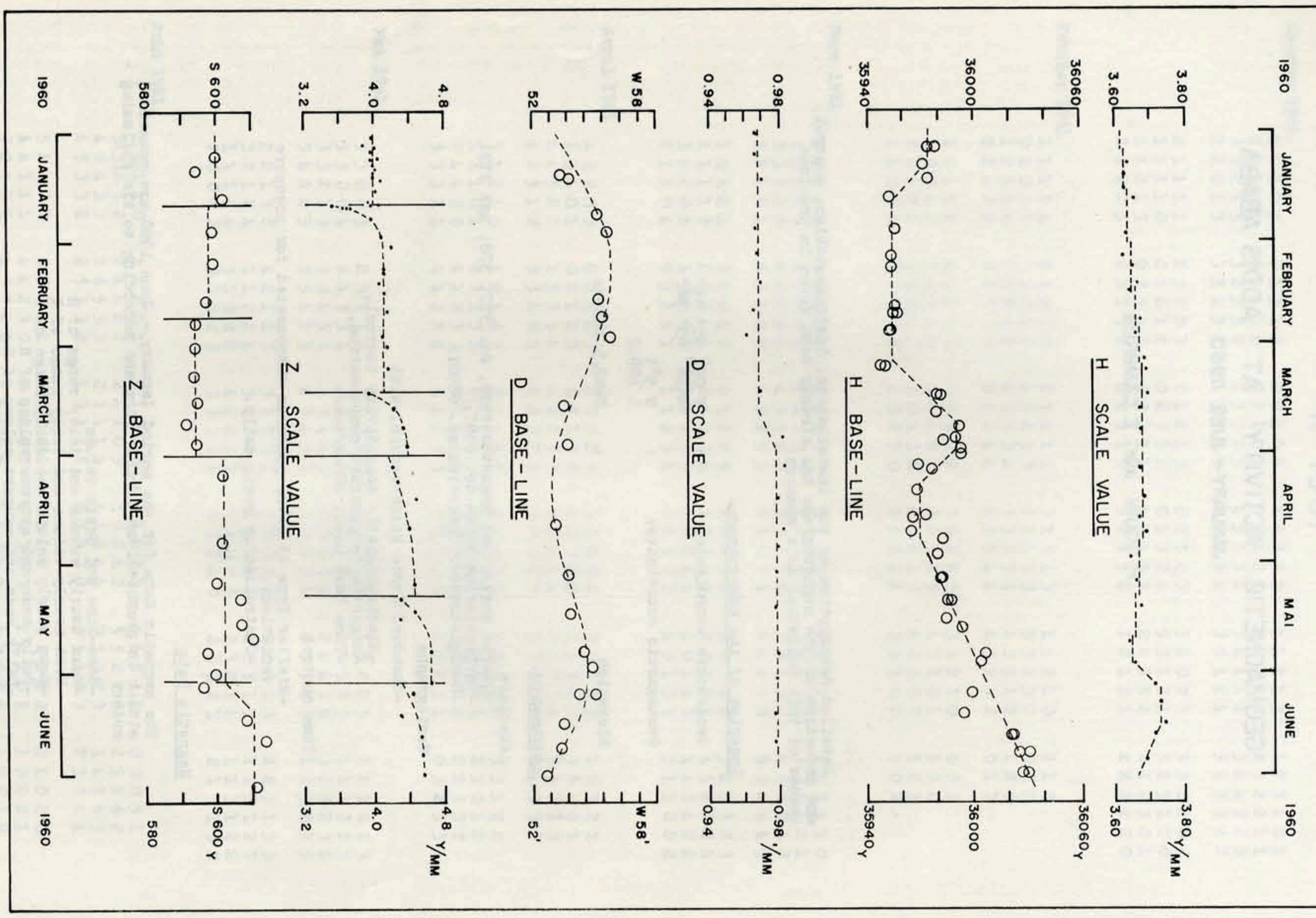


FIG. 1

HORIZONTAL COMPONENT OF TERRESTRIAL MAGNETIC FIELD

MEAN VALUES FOR PERIODS OF SIXTY MINUTES
UNCORRECTED FOR NON-CYCLIC VARIATIONS

$H = 36,000_{\gamma}$ (0.36 C.G.S. UNIT) + ...

H I — JANUARY 1960

DATE \ U.T.	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24	RANGE
1 Q	082	083	085	092	117	152	194	221	226	209	178	143	111	096	096	094	090	090	088	086	086	085	083	082	149
2	081	079	077	081	108	157	214	241	230	204	165	118	075	062	079	096	089	086	081	080	084	083	080	077	191
3	076	080	078	074	091	132	178	223	250	235	213	173	143	108	083	076	075	074	087	090	092	094	088	085	184
4	084	081	082	081	084	100	147	178	208	203	169	164	149	122	109	098	098	098	098	095	097	092	095	101	154
5	102	100	106	078	053	055	085	154	188	175	166	126	070	035	042	051	066	066	059	066	068	071	069	070	178
6	065	065	059	047	044	052	065	099	130	163	171	161	137	114	094	079	079	079	078	080	078	079	082	084	136
7	083	077	070	062	060	081	131	127	163	188	187	155	145	128	115	106	106	102	093	094	093	092	099	098	139
8	095	095	094	087	087	104	133	167	186	201	196	187	171	154	136	124	122	119	116	111	108	117	110	110	125
9 Q	107	100	096	095	107	130	157	190	221	232	211	186	160	148	141	126	119	117	115	120	109	106	098	100	145
10 D	105	112	114	112	132	160	224	271	181	164	105	049	036	047	021	013	001	014	027	032	073	049	029	032	268
11 D	039	042	045	050	073	095	124	142	124	070	043	046	051	045	055	054	042	053	053	056	058	061	063	065	148
12	069	067	064	063	085	124	164	159	146	109	106	088	078	070	074	075	062	063	069	066	061	093	070	066	122
13	063	062	063	068	088	126	167	210	212	168	117	070	054	067	079	073	070	072	076	103	080	073	080	088	171
14 D	076	062	077	077	094	134	195	201	244	143	051	-021	-005	069	092	093	083	087	085	012	-010	-004	-022	-047	403
15 D	-028	-004	004	014	-001	023	080	116	100	079	048	023	010	033	047	034	035	032	031	038	043	046	051	048	183
16	046	042	035	034	058	105	147	167	158	133	095	060	045	052	076	077	065	064	066	058	066	072	066	065	144
17	063	060	056	061	082	123	188	213	204	170	140	121	136	141	115	104	092	098	094	098	100	101	107	108	179
18	101	092	096	101	123	167	240	344	279	175	079	014	020	074	103	096	081	078	068	067	071	072	069	065	371
19	073	083	079	065	068	089	124	184	199	198	176	140	108	101	096	092	085	094	091	087	088	088	096	091	149
20	088	090	093	104	107	131	172	225	239	214	186	119	081	089	109	086	064	062	072	080	078	076	074	082	223
21 D	088	069	071	069	075	104	145	176	189	205	183	131	088	070	062	056	032	018	007	028	043	039	033	046	241
22	039	040	043	037	029	036	066	100	131	156	149	105	104	081	078	064	057	060	061	065	069	070	067	065	159
23	061	062	059	054	069	094	123	166	187	189	185	166	129	091	073	061	065	071	063	060	065	063	072	065	179
24	061	060	058	061	058	070	096	131	141	165	143	131	113	096	089	079	072	075	071	071	076	077	076	076	139
25	074	077	076	072	077	091	117	153	180	198	197	179	153	145	103	092	084	083	094	084	084	084	082	081	145
26	050	078	074	075	097	113	142	178	207	184	170	154	139	111	109	099	090	087	093	093	094	086	084	082	150
27	078	074	073	075	076	099	135	159	176	169	155	137	114	112	111	106	098	097	096	094	092	092	085	079	125
28	075	076	077	079	110	158	213	254	258	204	147	111	098	102	112	105	096	098	097	107	108	100	099	096	200
29	094	095	103	097	111	148	202	273	302	273	230	148	107	115	114	105	096	091	090	094	099	096	092	094	137
30 Q	091	085	082	084	106	161	236	296	320	295	246	192	137	109	113	117	108	105	103	101	101	100	099	097	243
31 Q	092	090	092	097	118	167	217	266	273	237	191	149	128	121	126	125	113	107	102	100	099	101	104	105	197
MEAN	73.3	73.4	73.6	72.5	83.4	112.3	155.5	193.1	201.7	184.1	154.8	120.2	99.5	93.8	92.0	85.7	78.5	78.7	78.2	78.3	79.1	79.2	76.8	76.0	183.1
Q	90.6	87.4	86.4	89.8	111.2	153.4	203.6	242.8	254.0	235.4	198.2	157.6	122.2	107.3	111.0	111.6	103.8	101.0	97.8	97.4	95.8	95.0	92.8	92.2	185.0
D	56.0	56.2	62.2	64.4	74.6	103.2	153.8	181.2	167.6	132.2	86.0	45.6	36.0	52.8	55.4	50.0	38.6	40.8	40.6	33.2	41.4	38.2	30.8	28.8	248.6

HORIZONTAL COMPONENT OF TERRESTRIAL MAGNETIC FIELD

MEAN VALUES FOR PERIODS OF SIXTY MINUTES
UNCORRECTED FOR NON-CYCLIC VARIATIONS

H = 36,000γ (0.36 C.G.S. UNIT) + ...

H2 FEBRUARY 1960

DATE \ U.T.	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24	RANGE
1	103	098	091	087	105	149	203	233	248	225	196	144	105	085	094	091	078	075	077	082	090	094	090	090	199
2	087	077	075	072	074	113	163	216	245	246	238	184	151	124	096	085	031	023	-012	-023	-016	-004	005	003	301
3	006	003	-002	026	038	074	116	170	194	200	165	140	094	065	063	038	031	013	014	038	037	041	046	056	203
4	049	044	045	039	059	067	138	158	167	145	150	136	119	102	091	076	068	057	042	055	057	059	064	069	150
5	067	069	064	064	073	100	149	183	178	189	210	161	110	104	084	052	032	049	050	044	052	058	067	058	246
6	064	050	048	063	073	095	119	152	162	143	155	152	145	125	106	085	061	053	062	071	076	076	087	087	151
7 Q	080	076	081	080	083	089	138	157	170	187	204	199	178	155	132	113	100	098	096	096	096	096	098	093	138
8	090	090	092	092	104	132	168	193	203	181	161	168	147	143	127	108	093	078	079	086	090	095	095	094	143
9 Q	084	088	091	090	093	111	136	152	162	158	163	173	180	171	151	136	128	123	119	109	106	113	112	113	107
10 Q	114	113	113	116	141	154	181	213	204	208	196	190	168	151	136	125	114	112	110	110	112	115	114	113	126
11	108	104	101	099	117	157	202	231	234	220	200	181	163	148	137	127	112	087	070	079	068	060	075	083	188
12	075	087	087	091	111	137	170	197	196	169	167	165	150	135	130	122	114	111	109	105	104	102	101	101	135
13	104	105	105	108	118	150	199	220	237	252	215	202	183	156	141	125	113	109	104	086	043	026	005	010	273
14 D	038	040	040	047	057	063	099	126	138	146	158	132	106	076	064	048	056	053	036	025	069	059	055	053	148
15	055	055	052	064	069	089	111	134	144	149	142	132	118	093	058	055	058	059	050	059	073	080	082	080	100
16 D	076	075	078	073	071	101	142	170	195	223	218	150	124	119	069	045	065	070	071	076	079	070	080	081	229
17 D	074	082	085	084	085	088	107	113	123	162	172	156	142	131	091	085	081	052	031	039	046	064	072	072	167
18 D	065	059	064	058	038	036	084	087	141	172	160	144	109	087	083	070	062	064	058	057	069	071	072	074	182
19	073	072	067	060	069	096	141	172	203	209	209	188	145	122	099	075	072	077	078	041	052	079	057	062	202
20	078	066	065	051	035	046	069	101	135	148	162	154	138	116	102	084	080	079	081	083	084	083	088	093	141
21 D	087	081	076	081	086	107	145	157	171	193	163	146	127	116	094	083	078	090	087	087	100	097	089	087	150
22	084	081	079	077	074	087	117	150	172	188	185	170	153	143	136	117	104	106	105	101	100	100	096	094	129
23	090	087	090	087	081	098	138	173	207	204	207	204	182	149	120	107	089	092	090	091	091	094	096	097	142
24 Q	096	093	084	079	070	089	124	156	180	198	195	180	165	149	133	121	110	105	102	099	096	093	094	094	137
25 Q	092	089	084	079	087	122	186	244	276	262	231	204	178	152	136	123	112	112	110	105	094	089	103	102	206
26	102	101	096	092	095	121	165	211	235	238	224	204	179	159	140	131	121	115	114	109	106	106	102	094	152
27	091	090	083	073	092	117	164	226	247	262	239	219	189	150	129	123	099	098	093	094	092	089	105	106	206
28	099	092	091	095	101	107	149	191	213	226	214	185	158	137	135	123	115	112	110	108	107	106	104	102	151
29	087	093	090	094	109	142	189	219	240	251	207	168	141	117	117	101	066	102	092	092	070	061	066	076	211
MEAN	79.9	77.9	76.4	76.6	83.0	104.7	145.2	176.0	193.8	198.4	189.7	170.0	146.4	126.9	110.1	95.7	84.9	81.9	76.8	76.0	77.3	78.3	80.0	80.6	172.9
Q	93.2	91.8	90.6	88.8	94.8	113.0	153.0	184.4	184.4	202.6	197.8	189.2	173.8	155.6	137.6	123.6	112.8	110.0	107.4	103.0	100.8	101.2	104.2	101.0	142.8
D	68.0	67.4	68.6	68.6	67.4	78.0	115.4	130.6	153.6	179.2	174.2	145.6	121.6	105.8	80.2	66.2	68.4	65.8	56.6	56.8	72.6	72.2	73.6	73.4	175.2

HORIZONTAL COMPONENT OF TERRESTRIAL MAGNETIC FIELD

MEAN VALUES FOR PERIODS OF SIXTY MINUTES
UNCORRECTED FOR NON-CYCLIC VARIATIONS

H = 36,000γ (0.36 C.G.S. UNIT) + ...

H3 MARCH 1960

DATE \ U.T.	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24	RANGE
1	082	082	085	085	091	103	154	214	230	232	207	183	146	125	118	109	089	071	060	058	060	060	065	070	215
2 D	067	068	080	069	064	082	131	198	211	193	171	166	114	095	094	093	075	078	060	051	054	068	093	083	185
3 D	077	076	079	070	064	082	117	147	170	179	138	145	112	102	071	055	060	068	063	065	063	060	060	079	161
4	079	073	073	073	078	102	136	160	162	170	168	146	116	086	072	063	051	032	032	051	060	058	084	075	151
5	071	070	070	063	065	092	125	133	154	158	163	150	136	122	110	104	099	096	088	071	066	079	090	098	103
6	097	084	087	090	108	137	179	225	253	243	210	191	169	143	120	108	090	087	091	085	088	087	087	082	194
7 Q	082	082	082	080	091	127	167	199	207	202	189	178	175	160	140	124	116	109	112	108	107	108	110	107	214
8	108	105	106	104	125	166	206	243	258	238	211	180	151	122	102	067	064	068	076	075	086	086	082	088	148
9	095	096	094	092	098	126	140	173	189	198	152	155	136	135	126	107	105	096	093	090	088	090	091	090	220
10	093	091	093	090	098	129	141	227	236	167	103	110	105	108	109	084	058	060	039	060	071	075	078	084	228
11 D	081	084	088	089	107	136	169	203	201	201	191	107	079	088	094	093	060	026	037	047	064	064	064	072	181
12	071	074	072	064	074	116	165	209	215	185	161	133	120	118	117	094	077	075	079	084	082	083	084	082	164
13 Q	079	076	076	074	085	125	180	212	231	227	196	167	141	120	108	100	093	090	096	085	080	085	167	093	170
14	091	090	086	081	096	129	167	201	237	225	201	183	166	146	130	130	122	116	116	113	112	111	113	121	290
15	112	112	107	099	101	133	195	253	277	267	219	190	160	132	114	099	057	039	010	036	033	021	030	016	229
16 D	003	010	025	035	-007	008	034	080	150	130	085	107	073	063	066	054	035	030	013	002	044	031	032	067	174
17	054	051	054	048	058	091	134	169	185	197	172	141	108	089	082	078	068	069	066	071	079	072	072	074	202
18	076	073	068	066	066	105	147	216	229	230	209	170	136	116	109	104	098	098	098	096	096	094	097	104	188
19	098	097	092	085	099	128	167	210	240	239	215	176	153	118	098	093	081	091	095	097	093	094	098	098	140
20 Q	099	097	097	092	101	128	169	204	217	217	197	184	167	149	134	123	114	110	109	107	107	108	105	104	140
21	107	107	103	095	095	124	164	202	225	219	222	213	180	132	114	116	112	108	108	106	105	105	106	106	126
22 Q	105	099	098	101	111	139	175	203	216	210	189	175	161	148	141	132	125	119	113	114	112	111	113	116	164
23 Q	120	112	105	100	117	165	216	248	256	238	221	209	190	170	149	133	124	119	118	115	115	117	125	122	190
24	116	115	121	125	134	135	219	257	247	237	171	161	156	154	156	132	100	101	100	104	088	107	113	104	210
25	100	100	097	099	122	169	225	270	270	238	196	158	139	132	127	118	110	107	104	098	101	103	105	101	191
26	102	100	101	101	131	189	254	270	234	171	125	113	111	137	137	134	119	117	118	114	113	113	113	116	193
27	116	113	116	116	121	168	217	274	283	260	212	161	137	135	137	128	117	112	112	109	107	107	109	109	186
28	108	108	104	100	120	173	219	248	269	238	186	125	125	132	139	113	064	068	077	071	096	091	089	075	247
29	075	083	077	067	079	122	196	306	225	175	145	134	132	133	122	107	095	093	094	093	095	091	098	115	279
30	117	106	097	088	109	150	213	272	304	268	210	192	163	135	129	104	067	051	039	025	020	017	033	054	315
31 D	073	083	069	062	084	124	159	165	141	093	152	120	043	065	086	059	-052	-141	-061	-073	-033	-031	-073	-025	472
MEAN	88.8	87.6	87.2	84.0	93.1	125.9	170.3	215.8	223.3	207.9	180.2	158.8	135.5	122.9	114.5	101.9	83.6	76.2	76.0	75.1	79.1	79.5	84.9	86.5	202.3
Q	97.0	93.6	91.6	89.4	101.0	136.8	181.4	213.2	225.4	218.8	195.4	182.6	166.8	149.4	134.4	122.4	114.2	109.4	109.6	105.8	104.2	105.2	124.0	108.2	175.6
D	60.2	64.2	68.2	65.0	62.4	86.4	123.6	158.6	174.6	159.2	147.4	129.0	84.2	82.6	82.2	70.8	35.6	12.2	22.4	18.4	38.4	38.4	35.2	55.2	231.4

HORIZONTAL COMPONENT OF TERRESTRIAL MAGNETIC FIELD

MEAN VALUES FOR PERIODS OF SIXTY MINUTES
UNCORRECTED FOR NON-CYCLIC VARIATIONS

H = 36,000γ (0.36 C.G.S. UNIT) + ...

H4 APRIL 1960

U.T. / DATE	0 1	1 2	2 3	3 4	4 5	5 6	6 7	7 8	8 9	9 10	10 11	11 12	12 13	13 14	14 15	15 16	16 17	17 18	18 19	19 20	20 21	21 22	22 23	23 24	RANGE
1 D	-118	-146	-118	-013	-057	-068	-013	061	077	-031	-083	-043	-117	-215	-331	-273	-335	-344	-318	-248	-269	-238	-162	-156	661
2	-154	-117	-103	-109	-094	-077	-077	-103	-098	-069	-083	-071	-025	009	012	-004	-010	-007	-003	000	004	005	012	039	218
3 D	063	008	014	012	-008	033	-016	-026	032	087	093	093	065	027	013	008	013	013	010	012	014	013	013	015	207
4	016	015	027	015	005	055	107	161	169	165	144	119	081	082	062	051	038	036	035	043	036	034	052	046	232
5	051	060	063	054	051	045	121	195	197	171	164	133	100	111	066	048	038	032	029	042	053	050	055	056	290
6	052	050	047	044	049	096	134	179	168	175	148	130	106	096	095	087	098	097	090	082	061	055	055	063	161
7	068	068	058	055	053	091	152	188	192	180	156	126	102	098	104	091	062	035	-006	003	029	043	070	065	213
8	059	052	058	056	057	108	177	164	196	139	111	077	067	080	082	071	056	067	072	073	070	072	073	066	171
9 Q	070	061	065	069	094	131	161	190	207	150	136	113	096	096	091	083	077	077	078	077	078	081	084	079	190
10	078	089	096	102	122	147	201	208	220	223	186	144	099	074	084	078	061	058	080	083	035	026	019	075	259
11	052	042	040	036	047	077	081	167	177	175	143	125	093	094	102	080	062	056	054	051	052	046	056	053	167
12	055	074	072	056	059	105	155	184	172	142	103	070	062	049	057	056	049	042	042	046	049	054	066	078	177
13	069	055	059	075	110	131	169	194	152	135	125	108	090	078	073	071	064	062	056	058	060	047	050	057	170
14	066	066	060	055	055	091	153	176	188	177	154	103	079	077	079	074	066	063	064	054	055	061	073	069	158
15	066	059	053	053	064	064	108	170	194	196*															
16							178	223	245	229	198	153	091	044	023	-013	-028	-001	017	016	020	038	037	033	288
17	069	043	047	060	075	108	141	180	186	169	113	090	083	082	086	082	075	053	038	035	036	051	048	051	179
18	050	054	059	055	065	110	146	159	177	182	138	114	102	092	085	073	067	074	080	083	080	079	079	082	168
19 Q	079	074	072	072	080	114	159	189	198	202	193	169	142	118	108	100	092	089	086	086	083	081	082	081	138
20 Q	078	076	076	070	070	100	144	192	214	218	207	182	152	123	106	100	094	089	089	089	088	087	087	089	156
21 Q	086	086	084	080	085	123	177	212	221	211	193	165	152	136	128	121	118	114	109	111	102	102	101	100	146
22 Q	102	100	096	096	111	153	190	213	196	176	170	157	149	142	131	111	103	102	102	097	100	097	097	097	132
23	095	093	091	093	109	172	221	249	248	230	212	180	162	153	144	131	115	107	110	109	088	060	034	007	258
24 D	000	-034	-052	-051	-039	021	091	137	122	103	104	068	057	005	016	021	020	-007	-016	-021	-014	036	030	010	221
25	016	047	033	021	048	091	115	152	144	101	102	038	010	007	013	-002	-014	015	-003	-007	-005	019	032	043	236
26	041	039	045	050	066	105	152	168	157	120	109	082	076	065	051	041	025	016	015	011	018	026	030	056	180
27	048	042	042	053	082	119	161	171	167	151	121	087	072	062	063	056	052	051	047	042	051	-003	000	038	193
28 D	007	-013	019	-003	-006	049	130	092	108	044	000	-040	-035	-017	-023	-064	-083	-090	-084	-053	-002	006	005	019	259
29	018	035	033	026	030	020	069	065	075	080	093	093	062	051	031	038	024	026	019	021	031	036	046	061	117
30 D	068	066	052	057	049	064	102	104	100	115	144	137	158	-005	-126	-130	-122	-399	-372	-336	-293	-235	-178	-148	817
MEAN.	43.1	39.4	40.9	42.7	49.4	82.0	126.3	153.8	160.0	144.9	123.9	100.1	80.4	62.6	52.6	40.9	30.2	18.1	17.9	22.7	24.5	28.6	36.1	42.2	233.2
Q	83.0	79.4	78.6	77.4	88.0	124.2	166.2	198.6	207.2	191.4	173.2	157.2	138.2	123.0	112.8	103.0	96.8	94.2	92.8	92.0	90.2	89.6	90.2	89.2	152.4
D	4.0	-23.8	-17.0	0.4	-11.6	19.8	58.8	73.6	87.8	63.6	51.6	43.0	25.6	-41.0	-70.2	-87.6	-101.4	-165.4	-156.0	-129.6	-112.8	-83.6	-58.4	-52.0	433.0

HORIZONTAL COMPONENT OF TERRESTRIAL MAGNETIC FIELD

MEAN VALUES FOR PERIODS OF SIXTY MINUTES
UNCORRECTED FOR NON-CYCLIC VARIATIONS

H = 36,000γ (0.36 C.G.S. UNIT) + ...

H5 MAY 1960

U.T. / DATE	0 1	1 2	2 3	3 4	4 5	5 6	6 7	7 8	8 9	9 10	10 11	11 12	12 13	13 14	14 15	15 16	16 17	17 18	18 19	19 20	20 21	21 22	22 23	23 24	RANGE
1 D	-136	-100	-051	-077	-051	-039	-021	-021	-003	-020	017	028	026	018	012	002	-013	-010	-006	-011	-009	020	014	012	015
2	010	002	-004	-004	052	066	102	146	170	166	132	100	080	056	048	049	047	050	053	053	060	058	057	058	226
3	056	053	053	050	045	062	096	132	149	168	163	147	131	115	093	073	069	063	072	069	069	066	069	066	137
4 Q	067	067	067	067	074	097	136	173	188	177	173	134	111	106	101	092	088	084	082	077	071	064	066	070	016
5	072	081	068	081	099	134	176	198	196	188	162	140	122	112	107	097	091	087	083	076	082	081	074	073	151
6 D	098	095	081	089	099	132	170	177	166	167	131	081	067	037	042	053	040	035	017	-030	-020	-021	002	-006	252
7 D	021	047	043	029	063	080	102	138	161	146	136	124	138	069	056	060	039	013	031	045	035	039	046	055	264
8 D	060	052	048	058	114	137	195	183	228	133	005	078	041	-012	-077	-140	-085	-043	-039	-014	-015	-002	005	035	131
9	033	036	048	056	069	099	127	137	170	160	144	068	054	051	047	040	041	044	044	046	050	051	053	054	176
10	054	052	049	060	079	118	152	170	161	153	135	112	093	085	078	064	063	064	067	072	071	066	062	077	134
11	079	069	080	093	137	161	192	212	151	104	122	120	099	083	076	064	060	061	063	057	052	050	070	063	200
12	061	058	061	066	078	115	143	191	193	170	139	114	083	083	083	074	061	064	071	073	074	073	067	075	175
13	074	068	071	075	097	145	214	232	237	230	188	150	118	101	087	082	078	073	072	070	082	073	069	067	191
14	066	072	064	064	081	120	182	226	239	213	194	160	121	088	078	074	069	077	082	081	078	083	084	081	195
15	079	079	080	081	088	114	164	191	213	217	206	147	100	082	079	088	082	083	083	085	081	082	080	081	162
16	080	081	083	080	087	117	176	217	252	236	201	189	170	164	168	120	104	071	081	090	137	133	135	112	216
17	096	109	108	106	118	145	206	218	229	204	159	137	106	095	093	093	079	089	096	096	094	094	093	093	194
18 Q	094	092	089	092	099	122	135	167	179	174	162	146	137	116	117	109	104	100	100	100	102	099	095	092	096
19 Q	093	096	096	108	129	148	173	205	193	180	161	141	122	111	104	102	099	097	095	093	093	095	098	099	134
20 Q	099	093	095	097	100	114	153	183	202	201	175	140	115	106	113	115	112	110	109	108	108	106	106	103	120
21	101	101	101	106	113	142	179	203	214	201	185	154	125	108	093	104	104	102	102	101	100	101	100	101	140
22 Q	100	098	098	099	099	119	160	187	192	177	164	149	141	122	116	125	126	123	123	124	120	117	115	116	104
23	119	117	115	120	129	160	183	193	186	171	170	156	153	143	137	115	098	082	075	077	083	095	087	088*	138
24							128	053	105	105	103	109	089	078	061	048	041	039	039	049	065	049	056	073	128
25	059	059	064	071	084	101	117	161	177	169	160	134	108	076	057	074	062	053	053	062	063	059	054	059	145
26							150	166	145	138	126	108	099	088	081	078	065	076	074	071	073	071	074	079	125
27	084	088	064	063	048	085	138	184	200	188	160	127	098	086	078*										
28										183	173	148	121	102	093	087	086	086	084	085	127	120	100	095	105
29 D	090	103	126	070	062	106	144	188	195	194	174	146	129	137	104	083	073	077	081	069	048	059	070	083	203
30	103	104	096	109	106	122	157	171	168	143	142	125	099	078	057	051	047	049	054	055	062	067	068	071	147
31	071	069	068	077	077	087	113	157	203	231	242	215	186	151	137	121	121	112	110	109	106	114	105	094	181
MEAN	67.3	69.3	70.0	70.9	84.8	110.9	148.1	171.2	182.0	196.9	151.7	129.9	109.0	91.5	81.3	72.2	68.4	66.9	68.4	67.9	71.4	72.1	72.5	74.0	153.4
Q	90.6	89.2	89.0	92.6	100.2	120.0	151.4	183.0	190.8	181.8	167.0	142.0	125.2	112.2	110.2	108.6	105,8	102.8	101.8	100.4	98.8	96.2	96.0	96.0	94.0
D	26.6	39.4	49.4	33.8	57.4	83.2	118.0	132.4	149.4	122.0	92.8	91.4	80.2	49.8	27.4	11.6	10.8	13.8	16.8	11.8	7.8	19.0	27.4	35.2	173.1

HORIZONTAL COMPONENT OF TERRESTRIAL MAGNETIC FIELD

MEAN VALUES FOR PERIODS OF SIXTY MINUTES
UNCORRECTED FOR NON-CYCLIC VARIATIONS

H = 36,000$_\gamma$ (0.36 C.G.S. UNIT) + ...

H6 JUNE 1960

U.T. / DATE	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24	RANGE
1	090	102	086	084	070	081	091	125	147	252	207	169	120	073	070	077	081	083	079	074	077	080	081	084	233
2 Q	091	088	079	067	061	072	121	174	196	194	173	157	140	134	128	119	114	112	111	108	105	107	109	108	152
3	108	102	099	095	098	119	153	183	204	204	197	188	162	145	135	138	139	136	120	115	107	112	113	101	119
4 D	098	101	105	149	121	078	121	089	065	133	118	139	141	121	088	076	071	069	073	082	089	084	074	079	151
5	064	061	057	043	043	034	065	089	098	131	119	088	081	063	062	061	051	054	069	086	098	099	093	092	149
6	084	086	095	089	070	091	124	186	170	191	186	141	133	115	113	107	096	102	103	106	108	107	106	092	157
7	108	110	098	095	113	131	176	212	235	184	151	163	159	140	116	108	105	101	105	119	114	108	108	106	169
8	103	096	097	127	102	102	119	114	175	171	192	144	133	129	120	112	107	104	094	093	083	085	104	104	146
9	095	114	105	113	123	153	172	203	212	180	178	151	145	126	105	099	101	101	110	107	102	103	103	104	151
10 Q	099	094	098	101	112	150	192	212	217	211	195	171	150	127	113	109	108	104	108	109	108	108	102	107	136
11 Q	109	105	110	108	142	174	225	249	251	231	203	180	147	120	113	117	119	119	118	116	116	115	116	117	101
12 Q	117	114	118	122	143	172	228	270	297	294	265	229	186	150	138	137	137	129	127	122	119	123	126	126	203
13	126	120	123	120	125	155	211	247	246	254	243	207	166	141	133	129	125	120	121	123	123	123	123	124	155
14	126	121	127	128	121	152	200	212	240	244	223	195	129	082	076	096	103	103	101	102	096	089	097	102	188
15	103	103	103	095	083	103	154	189	210	190	164	141	116	103	106	110	101	098	092	092	101	104	104	104	197
16 Q	105	108	105	098	110	136	168	196	226	230	217	201	173	151	133	117	115	113	111	113	111	111	111	110	145
17	112	107	102	107	122	140	166	187	202	204	200	188	169	148	132	119	108	099	105	111	114	114	110	115	116
18	115	106	115	120	132	159	185	210	232	227	205	162	141	120	106	119	126	125	116	122	120	120	127	120	143
19	122	110	107	116	104	104	135	139	141	132	141	120	109	104	079	075	079	076	078	076	076	084	084	093	84
20	091	091	090	100	104	121	141	163	174	156	146	139	132	116	109	099	103	108	105	101	101	098	097	098	91
21	107	111	107	094	104	118	153	175	168	156	141	105	091	092	095	088	072	071	069	071	075	073	078	089	123
22	095	096	100	117	119	133	146	168	180	163	162	144	124	110	101	099	100	104	105	104	094	098	069	072	113
23	094	100	094	105	122	150	184	197	202	197	172	144	123	110	107	110	094	091	087	085	090	092	099	098	130
24	099	100	102	108	107	143	174	193	186	180	178	163	145	125	109	102	099	092	081	091	102	099	100	105	129
25	111	105	108	109	123	137	163	202	215	204	183	153	110	080	085	088	091	101	078	066	067	070	095	082	176
26	082	088	103	096	079	103	137	146	173	155	156	140	131	117	110	099	097	097	100	098	094	098	068	099	125
27 D	095	105	115	060	037	020	063	149	186	171	159	140	108	084	075	074	082	067	052	052	059	066	087	090	236
28 D	080	093	088	075	054	108	129	160	205	206	222	156	092	077	068	062	055	046	048	061	067	068	065	067	154
29 D	073	073	077	094	127	125	116	185	153	176	179	171	153	128	111	098	091	087	086	098	110	125	088	055	204
30 D	065	067	028	025	-016	-003	065	121	146	159	148	131	114	083	076	069	058	084	078	091	057	073	078	070	261
MEAN	98.9	99.2	98.0	98.3	98.5	115.4	149.2	177.2	191.7	192.7	180.8	157.3	134.1	113.8	103.7	100.4	97.6	96.5	94.3	96.5	96.1	97.9	97.2	97.1	120.1
Q	104.2	101.8	102.0	99.2	113.6	140.8	186.8	208.2	237.4	232.2	210.6	187.6	159.2	136.4	125.0	119.8	118.6	115.4	115.0	113.6	111.8	112.8	112.8	113.6	141.3
D	82.2	87.8	82.6	80.6	64.6	65.6	98.8	140.8	151.0	169.0	165.2	147.4	121.6	98.6	83.6	75.8	71.4	70.6	67.4	76.8	76.4	83.2	78.4	72.2	96.3

MAGNETIC DECLINATION

MEAN VALUES FOR PERIODS OF SIXTY MINUTES
UNCORRECTED FOR NON-CYCLIC VARIATIONS

D = W 00° + ... (IN TENTHS OF A MINUTE)

DI JANUARY 1960

U.T. / DATE	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24	RANGE
1 Q	418	423	419	437	448	441	424	410	402	398	393	403	395	403	418	420	415	412	411	412	411	412	413	415	59
2 Q	421	422	424	433	446	444	430	426	421	414	401	397	397	412	421	424	411	411	440	439	411	412	412	415	49
3	421	425	428	431	437	436	425	422	419	416	412	413	407	402	415	424	418	414	413	415	412	412	412	411	39
4	412	416	420	424	427	434	423	416	423	423	426	411	416	406	419	424	413	415	416	418	416	419	418	420	20
5	422	426	427	426	426	430	419	404	397	400	393	390	391	398	406	414	404	407	412	411	407	406	401	392	39
6	410	413	411	415	432	441	436	441	453	445	425	410	405	405	408	417	418	420	416	415	416	415	414	414	49
7	416	416	418	417	416	409	402	408	426	429	423	416	419	420	424	429	426	425	421	419	418	416	419	418	24
8	417	416	417	423	436	443	433	434	435	436	417	409	412	422	429	430	427	424	423	422	424	420	417	419	37
9 Q	419	423	426	428	430	424	421	418	420	418	405	401	411	421	428	429	425	425	426	425	426	421	421	423	25
10 D	429	432	438	438	448	445	453	446	427	404	397	399	400	412	409	407	389	406	412	411	409	402	406	413	63
11 D	420	423	433	434	431	430	421	424	428	420	420	410	408	413	422	417	407	417	419	420	420	419	420	422,	29
12	427	428	432	434	437	436	426	430	458	471	445	421	413	416	422	431	422	423	421	421	414	418	414	421	61
13	425	432	437	441	437	431	412	402	402	393	386	396	412	422	430	425	422	421	420	417	410	412	419	424	55
14 D	436	443	437	451	463	453	440	446	446	414	401	406	427	434	434	425	419	424	427	412	404	397	387	400	78
15 D	422	425	431	438	454	465	455	449	439	425	411	403	401	410	430	428	422	422	423	422	422	422	424	425	66
16	427	429	433	439	439	426	414	415	433	426	409	404	409	418	426	436	429	426	429	428	429	429	424	423	36
17	430	440	440	446	451	430	407	402	406	407	407	417	417	420	427	430	428	429	427	434	434	433	434	436	49
18	441	441	447	452	460	465	472	457	433	411	396	399	418	441	438	431	422	426	428	425	431	430	431	431	68
19	438	435	435	436	441	436	424	439	445	430	412	409	412	416	429	437	431	432	436	436	435	435	437	436	35
20	437	440	443	449	454	446	446	447	459	459	440	430	438	437	443	443	434	429	431	433	435	433	437	437	37
21 D	450	442	453	453	438	439	440	440	454	443	417	393	404	411	418	429	421	416	421	421	423	428	424	425	59
22	429	433	434	428	419	420	424	436	449	444	415	412	422	429	438	437	429	432	432	432	432	432	430	431	31
23	436	441	440	443	444	429	399	404	409	415	419	420	416	413	425	435	435	431	433	433	432	433	434	436	42
24	444	446	446	444	445	436	412	405	421	424	415	421	426	427	427	441	437	434	437	439	441	441	442	444	42
25	445	447	447	445	446	437	413	406	422	425	416	422	427	428	428	442	438	435	438	440	442	442	443	445	42
26	449	451	455	457	457	448	439	436	440	443	433	429	437	442	443	445	444	444	439	441	440	442	443	443	30
27	449	451	454	458	457	449	436	419	421	422	420	429	440	447	450	451	447	444	444	444	444	443	443	444	37
28	447	450	454	463	473	466	450	433	417	416	418	423	427	439	450	450	442	442	444	445	444	444	447	447	56
29	451	454	462	471	480	469	451	438	428	426	421	418	424	436	435	451	445	443	441	444	444	442	441	444	67
30 Q	448	453	460	468	483	478	460	443	418	409	410	400	412	428	443	455	448	448	446	445	444	445	445	448	77
31 Q	449	451	455	463	469	473	451	431	425	418	418	425	432	440	447	451	446	445	445	450	450	450	449	450	55
MEAN	431.8	434.4	437.3	441.5	445.9	442.2	430.9	426.7	428.3	423.4	413.6	410.8	415.3	421.5	428.5	432.5	426.3	426.5	428.1	428.0	426;5	426.0	425.8	427.5	47.0
Q	431.0	434.4	436.8	445.8	455.2	452.0	437.2	425.6	417.2	411.4	405.4	405.2	409.4	420.8	431.4	435.8	429.0	428.2	433.6	434.2	428.4	428.0	428.0	430.2	53.0
D	431.4	433.0	438.4	442.8	446.3	446.4	441.8	441.0	438.8	421.2	409.2	402.2	408.0	416.0	422.6	421.2	411.6	417.0	420.4	417.2	415.6	413.6	412.2	417.0	59.0

MAGNETIC DECLINATION

MEAN VALUES FOR PERIODS OF SIXTY MINUTES
UNCORRECTED FOR NON-CYCLIC VARIATIONS

D = W 00° + ... (IN TENTHS OF A MINUTE)

D 2

FEBRUARY 1960

DATE \ U.T.	0 1	1 2	2 3	3 4	4 5	5 6	6 7	7 8	8 9	9 10	10 11	11 12	12 13	13 14	14 15	15 16	16 17	17 18	18 19	19 20	20 21	21 22	22 23	23 24	RANGE
1	453	456	456	464	465	458	456	449	437	429	427	424	423	427	434	447	442	439	439	444	444	445	445	447	50
2	448	446	448	449	454	448	440	435	431	422	421	413	420	431	435	445	454	445	442	438	436	431	430	428	39
3	436	437	441	438	438	441	441	448	449	448	445	448	438	434	441	445	439	438	431	436	432	428	426	420	30
4	428	431	440	440	446	441	441	441	453	448	442	435	429	421	424	438	438	440	441	438	435	436	438	442	34
5	444	448	446	448	451	454	453	450	451	457	450	426	433	438	443	443	441	436	437	435	435	431	428	424	39
6	425	432	438	445	450	454	445	442	440	441	438	428	422	430	438	442	440	436	438	440	436	436	441	446	29
7 Q	451	457	463	462	459	451	448	442	440	440	439	440	431	431	435	445	441	439	439	441	442	442	445	448	33
8	448	451	457	457	460	457	454	449	443	434	429	425	431	443	441	441	435	438	438	438	440	441	443	447	37
9 Q	446	450	455	451	454	450	445	441	438	441	444	443	445	448	447	448	449	445	444	444	446	448	448	451	19
10 Q	455	459	463	466	465	451	443	446	435	441	438	433	438	444	448	448	441	439	441	441	443	445	448	449	30
11	451	457	457	457	457	448	441	435	434	432	440	440	446	450	450	450	445	435	438	440	435	434	441	448	26
12	448	457	458	464	466	459	445	438	438	435	428	425	426	438	448	455	449	445	445	445	444	445	448	449	42
13	453	457	457	465	472	476	474	463	455	435	425	423	429	438	442	448	446	445	448	440	431	430	422	428	62
14 D	440	448	452	454	465	466	468	464	457	451	445	435	432	433	434	438	437	438	432	431	428	428	434	438	35
15	441	443	445	449	454	448	441	447	447	443	433	428	425	425	424	435	435	431	435	441	444	444	445	444	32
16 D	441	444	444	450	451	445	443	444	448	442	441	428	421	427	421	430	438	440	442	444	444	440	445	445	24
17 D	444	450	453	457	460	458	458	453	459	459	449	434	429	427	431	437	438	440	436	437	435	434	427	427	38
18 D	427	434	429	429	439	447	449	447	443	442	437	427	423	428	435	431	430	434	423	430	440	441	442	440	29
19	440	442	446	443	447	447	447	442	439	436	429	425	423	425	429	436	441	437	434	424	433	434	432	434	24
20	432	437	427	434	433	439	442	444	442	438	435	432	427	428	432	437	432	437	440	441	442	440	440	441	18
21 D	443	446	446	445	446	449	446	442	446	442	423	416	423	422	421	433	429	438	439	440	443	442	439	443	43
22	446	446	448	452	457	459	449	436	440	436	427	422	417	422	429	443	443	443	443	443	440	441	443	444	43
23	447	449	449	455	461	457	449	439	434	429	424	423	425	429	431	438	433	433	438	444	446	444	443	444	39
24 Q	444	446	449	451	456	456	452	446	443	443	441	433	429	429	436	446	446	443	442	443	446	443	443	445	32
25 Q	445	445	447	448	450	442	432	428	420	427	430	432	434	438	442	448	446	445	445	445	443	441	455	447	27
26	448	448	448	448	454	448	435	421	415	418	428	432	435	441	444	448	448	445	444	445	446	445	445	445	39
27	449	447	449	450	443	430	414	414	403	400	402	409	419	425	433	444	441	439	435	436	442	442	447	447	52
28	446	446	446	454	462	459	454	452	449	446	446	440	433	431	436	443	443	441	440	441	443	441	442	442	31
29	440	432	442	441	435	427	418	417	422	428	433	435	438	435	442	444	442	432	438	442	438	433	437	439	26
MEAN	443.4	446.2	448.2	450.6	435.4	450.5	445.6	441.9	439.7	437.3	434.1	429.4	429.1	432.3	436.1	442.3	440.8	439.2	438.9	439.6	439.7	439.1	440.0	441.1	34.6
Q	448.2	456.4	455.4	455.6	457.2	450.0	444.0	440.6	435.2	438.4	438.4	436.2	435.4	438.0	442.0	447.0	444.6	442.2	442.2	442.8	444.0	443.8	447.8	448.0	28.2
D	439.0	444.4	444.8	447.0	452.2	453.0	452.3	450.0	450.6	447.2	439.0	428.0	425.6	427.4	428.4	433.8	434.4	438.0	434.4	436.4	438.0	437.0	437.4	438.6	33.8

MAGNETIC DECLINATION

MEAN VALUES FOR PERIODS OF SIXTY MINUTES
UNCORRECTED FOR NON-CYCLIC VARIATIONS

D = W 00° + ... (IN TENTHS OF A MINUTE)

D 3

MARCH 1960

DATE \ U.T.	0 1	1 2	2 3	3 4	4 5	5 6	6 7	7 8	8 9	9 10	10 11	11 12	12 13	13 14	14 15	15 16	16 17	17 18	18 19	19 20	20 21	21 22	22 23	23 24	RANGE
1	441	438	435	440	445	439	432	432	426	439	440	439	434	431	436	444	441	437	437	435	432	432	436	435	18
2 D	431	427	427	434	437	434	431	428	428	436	444	441	428	424	427	434	434	434	431	430	431	432	436	434	15
3 D	430	430	428	425	423	420	415	416	425	430	433	431	421	417	423	427	430	433	430	435	435	435	433	435	23
4	432	433	435	436	436	439	440	439	436	442	448	456	448	440	432	424	429	425	427	431	432	431	432	429	29
5	428	430	428	430	430	428	424	422	428	431	438	435	431	433	437	438	440	438	438	434	433	435	435	434	15
6	435	437	441	451	452	446	437	430	429	432	439	440	435	427	420	428	432	430	431	428	429	433	434	434	34
7 Q	436	439	439	440	440	433	420	416	418	428	442	441	429	421	423	430	436	435	434	434	436	436	438	439	29
8	441	443	444	449	444	435	420	415	417	428	487	437	426	421	422	423	423	422	425	428	432	435	435	438	34
9	437	437	440	443	435	427	417	417	422	427	436	439	434	434	426	426	431	427	429	430	431	433	434	437	24
10	438	439	439	445	438	433	429	421	413	413	430	436	431	432	425	420	414	419	412	413	423	426	430	433	32
11 D	434	436	438	441	437	429	422	413	405	412	424	405	413	421	425	429	418	404	408	420	424	425	424	425	35
12	428	431	434	435	432	428	423	408	402	409	409	411	412	421	423	422	418	418	422	424	424	426	424	426	31
13 Q	425	428	430	430	421	412	402	399	399	407	413	415	418	423	426	428	423	421	422	422	423	423	426	428	32
14	429	429	430	432	429	422	411	405	402	401	410	417	416	419	426	434	432	429	427	426	427	426	425	427	32
15	426	428	429	431	428	419	408	400	391	399	408	413	412	419	428	434	430	418	408	405	408	407	405	398	41
16 D	387	395	390	409	405	412	407	407	407	411	416	416	408	414	424	421	410	400	397	388	397	409	408	417	36
17	418	421	425	431	429	423	416	411	407	416	423	423	419	415	416	416	413	411	410	406	408	414	415	419	24
18	422	420	423	426	428	417	405	402	389	391	397	403	405	411	417	419	418	417	417	417	418	418	419	418	34
19	419	420	420	426	426	417	417	394	386	394	407	414	406	406	408	410	414	415	415	414	414	417	420	419	42
20 Q	419	421	421	424	425	418	412	407	408	414	429	418	404	400	405	414	421	417	416	417	420	420	421	419	32
21	418	419	419	420	416	413	413	413	409	415	423	419	406	398	410	416	417	416	414	415	416	416	415	415	23
22 Q	416	417	419	422	420	415	416	413	413	421	426	426	416	403	404	413	417	416	414	415	416	417	416	416	19
23 Q	417	419	418	422	421	420	417	415	412	418	423	421	400	394	394	410	417	416	416	416	416	419	419	418	
24	418	423	417	422	417	419	419	412	402	409	420	427	412	399	405	414	412	415	413	412	412	416	415	412	29
25	411	412	414	417	412	412	409	405	404	413	419	421	400	396	429	407	413	413	410	410	413	415	413	412	23
26	413	413	413	409	404	407	402	390	386	393	402	409	406	400	407	417	414	412	414	416	414	416	413	413	29
27	412	413	413	417	412	412	403	395	399	406	414	416	413	412	416	416	417	416	415	413	415	413	412	412	20
28	413	412	414	416	415	416	407	398	395	391	389	399	402	409	417	416	405	408	409	409	406	403	405	405	29
29	403	405	402	403	406	408	409	398	396	406	397	395	395	402	411	415	412	408	405	408	408	405	403	400	20
30	398	401	408	418	415	416	416	411	406	402	401	400	395	391	400	402	398	398	398	395	394	390	390	392	24
31 D	394	389	386	389	397	404	407	400	397	402	423	384	399	422	443	435	414	397	404	396	385	363	327	313	14
MEAN	421.6	422.7	423.5	426.9	425.0	421.7	416.3	410.7	408.6	414.1	421.3	420.9	415.6	414.7	419.5	422.0	420.7	418.2	418.0	417.8	418.5	418.9	418.0	417.8	30.6
Q	422.6	424.8	425.4	436.6	425.4	419.6	413.4	410.0	410.0	417.6	426.6	424.2	413.4	408.2	410.4	419.0	422.8	421.0	420.8	420.8	422.2	363.0	364.0	444.0	27.8
D	415.2	415.4	113.8	119.6	419.8	419.8	416.4	412.8	412.4	418.2	428.0	415.4	413.8	419.6	428.4	429.2	421.2	413.6	414.0	413.8	414.4	412.0	405.6	404.8	44.6

MAGNETIC DECLINATION

MEAN VALUES FOR PERIODS OF SIXTY MINUTES
UNCORRECTED FOR NON-CYCLIC VARIATIONS

D = W 00° + ... (IN TENTHS OF A MINUTE)

D 4 — APRIL 1960

U.T. / DATE	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24	RANGE
1 D	288	361	362	334	362	370	373	388	413	426	439	404	383	350	370	365	348	351	340	348	348	343	348	353	103
2	358	355	338	317	311	333	376	401	409	405	394	398	412	410	407	403	403	399	394	392	391	391	389	394	97
3 D	400	383	397	391	369	363	359	354	370	371	378	384	388	393	399	397	399	397	394	391	392	392	390	390	51
4	391	394	397	399	392	388	386	384	383	379	375	377	370	378	385	391	391	386	391	396	397	381	393	394	30
5	399	406	406	420	418	406	406	410	411	401	397	401	399	404	389	374	384	393	398	399	402	399	399	399	45
6	398	397	396	392	389	390	389	386	391	399	400	397	392	390	397	402	406	406	406	402	391	387	392	396	22
7	392	395	392	400	399	407	405	402	410	415	416	412	405	398	395	395	395	376	367	376	386	390	397	398	46
8	398	396	395	390	387	388	385	376	385	388	393	392	392	391	394	396	393	398	396	401	400	401	401	403	25
9 Q	405	402	402	401	398	400	392	396	396	396	402	409	408	401	397	401	405	407	407	405	402	401	401	402	17
10	402	403	405	402	393	386	378	376	393	405	401	402	398	397	408	409	407	402	396	398	389	388	378	388	31
11	387	391	393	394	396	399	401	412	416	424	420	412	406	407	407	398	405	405	398	400	400	399	402	403	36
12	405	413	403	396	388	392	392	395	403	418	415	411	400	387	393	400	401	397	397	398	400	398	399	398	25
13	399	400	399	393	391	389	379	377	378	385	397	407	409	408	408	409	405	401	401	402	400	398	396	397	30
14	397	398	400	409	411	413	409	408	408	408	402	402	401	397	401	401	403	401	401	399	403	401	402	401	17
15	400	399	402	403	399	391	387	393	399	398															
16							398	399	406	405	411	409	404	390	390	392	392	387	395	397	392	398	399	401	
17	403	402	398	386	380	386	390	402	419	419	422	425	419	409	406	407	411	402	392	391	393	392	390	399	43
18	403	402	403	399	394	396	399	402	412	412	408	405	408	403	399	396	397	399	400	402	403	405	403	406	19
19 Q	404	405	403	394	393	404	409	411	419	422	419	419	417	404	396	401	405	406	404	403	403	404	403	403	26
20 Q	404	405	406	401	402	406	400	403	406	406	410	411	408	397	395	399	407	407	406	405	403	404	404	404	20
21 Q	404	405	407	402	400	403	407	411	411	404	401	399	394	394	400	411	417	414	413	412	410	409	412	411	25
22 Q	412	409	408	407	407	409	407	405	400	397	397	396	387	382	389	405	412	412	413	411	411	411	410	412	30
23	411	410	409	402	402	414	414	411	411	410	405	407	398	393	395	408	415	416	414	414	409	398	394	392	23
24 D	391	384	379	373	358	359	363	376	392	405	408	403	400	388	385	392	400	392	387	381	390	390	385	387	50
25	376	389	396	385	383	387	389	404	410	411	411	408	403	398	385	391	389	390	385	390	390	395	394	400	33
26	401	396	399	381	381	391	404	411	417	420	418	421	415	402	394	393	395	395	395	391	392	396	397	400	37
27	399	403	399	383	376	382	382	391	406	411	410	413	414	406	402	402	405	404	402	397	399	383	376	366	38
28 D	357	352	355	337	365	389	393	391	409	414	411	400	389	376	384	398	405	393	391	391	390	394	394	393	66
29	396	383	389	387	390	394	391	392	402	393	396	390	391	395	395	402	399	402	399	395	394	395	392	394	15
30 D	390	395	369	370	377	385	381	381	390	398	407	410	421	408	395	429	433	350	339	351	359	359	361	366	106
MEAN	392.1	294.2	393.3	387.9	386.6	390.3	391.3	394.9	402.5	404.8	405.6	404.3	401.1	395.0	345.1	398.9	404.4	396.1	393.7	394.4	394.4	393.0	391.1	394.8	39.5
Q	405.6	405.2	405.2	401.0	400.0	404.4	403.0	405.2	406.4	405.0	405.6	406.8	402.8	395.6	395.4	403.2	409.2	409.2	408.6	407.2	405.6	405.6	406.0	406.4	23.6
D	365.2	375.0	372.4	361.0	366.2	373.2	372.8	378.0	394.8	403.0	408.8	400.2	396.2	383.0	386.6	396.2	397.0	376.6	370.2	372.4	375.8	375.6	375.6	377.8	75.2

MAGNETIC DECLINATION

MEAN VALUES FOR PERIODS OF SIXTY MINUTES
UNCORRECTED FOR NON-CYCLIC VARIATIONS

D = W 00° + ... (IN TENTHS OF A MINUTE)

D 5 — MAY 1960

U.T. / DATE	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24	RANGE
1 D	366	366	365	356	360	368	376	384	398	394	400	398	392	391	394	393	390	390	390	387	385	389	393	393	58
2	396	396	395	388	376	384	384	385	385	379	360	367	376	386	395	394	398	403	401	398	399	398	398	399	30
3	403	405	406	406	409	417	415	418	413	404	397	393	388	384	391	398	403	408	408	407	407	406	405	404	36
4 Q	404	407	405	397	394	404	415	416	417	415	407	408	402	397	397	403	409	409	409	407	405	402	403	406	20
5	407	407	407	396	392	401	405	407	406	405	402	396	398	397	399	409	412	412	410	409	407	405	402	407	16
6 D	409	413	408	401	403	417	423	419	420	418	408	406	411	411	416	414	409	406	386	386	395	390	384	387	32
7 D	384	397	381	369	368	384	390	395	400	405	404	411	423	407	399	409	405	400	400	401	397	396	401	403	54
8 D	403	403	399	390	390	408	423	432	430	403	418	421	404	373	374	372	406	408	395	399	391	387	391	391	54
9	396	394	390	388	400	410	413	419	426	420	411	394	385	380	307	394	404	404	404	407	406	407	406	406	50
10	407	406	402	393	395	402	408	412	419	421	412	405	399	400	396	398	403	409	408	409	408	408	407	409	25
11	409	406	401	389	394	401	413	419	417	426	418	405	402	403	406	411	411	412	410	404	403	402	402	402	35
12	403	400	398	391	389	393	399	411	420	416	409	405	400	399	396	408	410	416	413	412	409	406	403	403	32
13	407	407	403	401	407	421	421	432	436	434	424	410	403	403	405	406	407	410	411	410	412	407	403	401	34
14	408	408	407	392	382	390	405	418	428	423	415	421	417	413	408	409	414	418	417	418	417	414	413	414	44
15	413	411	408	401	403	412	422	429	430	425	421	411	411	413	413	413	413	416	413	412	412	413	413	415	25
16	416	414	412	407	414	416	417	425	424	421	416	421	417	423	441	430	452	433	426	427	421	412	413	411	50
17	413	416	410	397	397	411	426	442	451	445	432	427	417	413	408	410	413	415	417	417	415	414	413	414	52
18 Q	413	414	410	400	402	412	415	423	425	420	423	416	413	405	410	413	416	417	419	417	420	420	420	419	19
19 Q	419	415	405	388	388	403	423	437	443	444	440	429	423	409	408	414	418	418	418	419	421	421	422	424	53
20 Q	424	420	417	410	416	421	432	441	442	441	432	420	408	397	400	414	422	422	420	421	422	419	423	423	40
21	424	422	415	398	399	406	419	428	431	433	425	419	418	414	402	418	423	423	422	422	419	419	416	417	33
22 Q	419	419	416	409	412	419	429	433	429	429	433	433	423	413	413	425	431	428	426	425	418	418	417	419	13
23	420	416	413	403	403	413	427	437	438	442	439	423	417	410	415	427	429	420	412	412	414	413	417*	415*	43
24							415	418	419	422	416	407	400	404	407	416	423	422	413	409	412	409	412	408	23
25	408	401	402	393	395	404	402	408	414	417	417	411	406	407	407	415	420	415	410	413	411	410	410	404	26
26							414	421	422	424	424	418	415	408	414	421	416	416	411	414	413	408	406	404	28
27	400	397	391	390	391	413	433	446	454	449	442	439	431	427											
28										429	421	414	414	414	416	417	420	418	416	417	421	408	410	414	34
29 D	397	389	397	389	388	405	418	431	434	435	435	431	422	423	412	415	421	422	423	421	415	411	413	419	46
30	423	422	415	398	391	396	411	422	434	435	427	417	401	397	388	392	400	411	416	420	422	422	423	421	45
31	420	419	414	399	393	401	415	424	430	435	435	429	431	430	435	428	430	425	420	417	414	415	409	406	42
MEAN	407.5	406.8	403.3	394.3	394.7	404.7	413.6	421.1	424.5	422.9	418.2	413.1	408.9	404.9	405.1	409.5	414.3	414.2	411.5	411.2	410.4	408.3	408.3	408.2	35.4
Q	415.8	415.0	410.6	400.8	402.4	411.8	422.8	430.0	431.2	429.8	427.0	421.2	413.8	404.2	405.6	413.8	419.2	418.8	418.4	417.8	417.2	416.0	417.0	418.2	29.0
D	391.8	393.6	390.0	381.0	381.8	396.4	406.0	412.2	416.4	411.0	413.0	413.4	410.4	401.0	399.0	400.6	406.2	405.2	398.8	398.8	396.6	394.6	396.4	398.6	48.6

MAGNETIC DECLINATION

MEAN VALUES FOR PERIODS OF SIXTY MINUTES
UNCORRECTED FOR NON-CYCLIC VARIATIONS

D = W 00° + ... (IN TENTHS OF A MINUTE)

D 6 — JUNE 1960

DATE \ U.T.	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24	RANGE
1	409	413	407	390	391	396	408	412	406	394	393	384	396	407	420	430	430	429	426	421	418	418	417	413	38
2 Q	412	412	413	408	409	413	418	420	420	416	409	409	412	413	413	420	425	427	427	423	422	420	420	420	18
3	419	418	415	410	407	412	419	418	419	415	410	403	407	415	420	428	432	429	422	421	419	416	414	411	30
4 D	411	413	410	400	391	395	406	405	418	419	422	421	419	419	425	437	431	428	425	419	415	416	402	411	40
5	411	408	411	407	403	404	405	409	415	415	419	412	415	415	411	413	414	418	415	415	417	419	418	416	17
6	409	406	400	394	393	411	422	430	434	431	431	418	417	412	411	417	420	421	421	421	418	418	420	422	34
7	416	418	414	398	397	406	410	414	421	431	431	434	424	416	413	419	424	424	421	414	420	419	419	418	39
8	416	413	407	397	396	404	418	423	423	433	430	431	425	417	413	420	425	421	417	413	408	411	417	419	32
9	421	420	410	389	373	383	409	425	430	422	419	423	420	416	413	416	420	420	414	416	417	418	419	418	56
10 Q	419	415	406	399	385	395	412	422	428	430	430	422	420	412	407	410	418	420	419	419	416	410	415	416	41
11 Q	416	416	407	399	396	406	422	432	428	432	435	426	420	416	412	412	420	420	421	421	421	420	422	420	35
12 Q	418	417	411	398	392	406	428	428	430	440	427	418	424	431	427	425	431	428	426	419	418	417	416	418	44
13	417	417	417	406	394	399	409	411	416	423	429	429	425	425	427	425	426	427	427	423	424	420	419	423	33
14	419	423	420	409	403	408	418	426	430	430	430	428	422	416	417	418	423	424	423	418	417	417	416	416	28
15	417	421	420	411	404	407	413	408	405	411	419	417	414	412	416	416	419	425	422	415	414	416	417	421	20
16 Q	417	415	415	403	386	388	402	408	409	408	399	397	404	410	413	414	417	418	420	419	416	415	418	418	32
17	414	417	413	405	401	403	411	417	420	423	421	417	419	417	414	412	412	421	420	417	417	417	417	415	24
18	414	412	413	396	387	396	410	427	431	429	425	413	409	409	416	421	426	426	428	419	416	413	416	416	45
19	413	415	411	400	390	396	400	402	402	402	402	402	405	405	405	412	415	412	412	406	406	409	410	412	23
20	409	407	404	394	389	397	408	416	421	424	424	414	407	404	409	412	417	418	420	419	416	414	413	411	34
21	411	409	401	384	374	386	398	404	416	427	430	428	427	423	417	420	416	411	411	409	410	406	403	402	49
22	399	392	388	382	376	383	397	410	416	422	425	427	420	411	411	417	419	420	419	414	408	409	407	401	48
23	399	396	389	380	371	380	397	419	426	430	427	421	423	418	419	420	414	414	413	409	408	405	402	399	60
24	400	397	394	384	383	394	406	408	406	400	403	408	410	414	413	414	418	417	412	407	408	405	400	400	36
25	397	393	397	387	381	382	409	425	432	435	424	414	417	417	409	411	411	406	399	402	406	400	401	396	48
26	392	385	379	379	376	382	398	413	427	426	420	422	418	410	403	403	411	411	411	408	402	400	396	396	54
27 D	392	390	375	364	355	365	391	405	404	405	407	410	407	404	400	401	406	401	400	403	403	388	389	388	52
28 D	388	391	390	380	377	384	397	408	420	422	417	413	407	401	399	403	403	399	400	393	390	389	384	387	45
29 D	387	387	377	361	363	370	381	397	402	411	407	407	405	399	401	402	402	403	405	407	412	413	383	376	57
30 D	375	375	377	380	366	367	381	393	403	404	409	411	411	405	399	397	391	398	397	402	388	387	390	391	41
MEAN	407.9	407.0	403.0	392.9	387.0	393.9	406.8	414.5	418.6	420.3	419.1	416.0	415.0	413.0	412.4	415.5	417.9	417.9	416.4	413.7	412.3	410.8	409.3	409.0	38.4
Q	416.4	415.0	410.4	399.4	394.2	401.6	416.4	422.0	432.0	425.2	420.0	414.4	416.0	416.4	414.4	416.2	422.2	422.6	422.6	420.2	418.6	416.4	418.2	418.4	34.0
D	390.6	391.2	385.8	377.0	370.4	376.2	391.2	401.6	409.4	412.2	412.4	412.4	408.8	405.6	404.8	408.0	406.6	405.8	405.4	404.8	401.6	398.6	384.6	390.6	47.0

VERTICAL COMPONENT OF TERRESTRIAL MAGNETIC FIELD

MEAN VALUES FOR PERIODS OF SIXTY MINUTES
UNCORRECTED FOR NON-CYCLIC VARIATIONS

Z = 600γS (0.006 C.G.S. UNIT) + ...

Z 1 — JANUARY 1960

DATE \ U.T.	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24	RANGE
1 Q	048	048	048	049	044	034	024	018	018	024	027	034	042	051	054	048	044	045	046	048	047	046	045	047	038
2 Q	048	048	048	049	047	036	032	034	037	041	042	050	061	063	059	052	047	048	048	048	048	048	048	048	034
3	049	049	049	048	046	038	032	027	022	026	029	037	038	039	048	048	044	044	046	048	044	046	047	048	031
4	048	050	050	050	054	054	049	056	061	060	052	044	049	055	057	054	048	050	051	050	050	051	048	050	024
5	052	052	052	051	055	054	043	032	031	027	028	035	040	045	049	048	045	048	048	048	047	047	047	048	029
6	051	049	051	053	058	052	044	042	035	022	011	008	017	024	033	040	040	040	040	041	042	042	044	044	052
7	045	046	048	047	048	047	045	051	047	040	039	046	050	049	049	047	043	043	041	040	040	040	043	044	015
8	044	044	044	046	049	044	036	038	040	033	027	028	033	042	042	040	039	039	039	039	039	039	040	041	026
9 Q	043	044	044	042	038	033	032	033	035	039	042	049	053	052	048	046	042	041	041	043	044	044	044	044	024
10 D	045	046	046	046	045	042	037	035	032	028	032	044	048	043	044	043	041	042	043	042	040	042	043	044	040
11 D	045	047	048	046	044	040	037	036	039	042	049	051	055	051	046	042	042	044	044	044	044	044	044	044	025
12	045	045	044	044	042	038	033	043	052	058	050	047	048	055	051	048	043	043	044	044	042	043	044	044	030
13	046	046	046	045	040	036	033	036	038	045	051	062	067	063	056	050	046	046	046	046	047	047	048	048	036
14 D	051	051	049	050	044	032	026	027	016	018	028	044	050	041	043	039	039	041	042	042	040	040	044	048	061
15 D	048	048	052	052	058	053	045	047	048	046	043	043	044	048	052	048	044	046	045	045	045	046	046	046	024
16	046	048	048	048	040	032	033	044	053	044	040	041	048	049	048	045	042	041	041	041	042	043	044	044	025
17	044	046	046	046	040	024	017	020	033	033	029	033	034	041	044	040	039	038	043	044	043	043	040	042	035
18	043	041	043	043	041	038	029	029	029	037	044	054	063	056	047	044	040	042	042	041	042	041	042	042	053
19	041	041	042	042	041	037	024	028	035	028	024	031	040	044	042	039	037	037	037	036	036	037	040	040	025
20	040	040	040	041	039	034	030	029	031	036	037	046	054	049	040	037	034	036	037	037	039	039	039	040	037
21 D	041	043	041	041	037	031	024	022	018	011	012	022	027	029	036	039	035	035	035	033	035	034	034	034	037
22	035	034	034	033	035	039	043	045	042	031	024	030	030	031	032	031	030	029	030	030	030	030	030	030	030
23	031	030	031	030	025	011	007	008	019	027	034	043	047	047	050	046	040	039	039	039	038	038	037	037	053
24	038	038	038	038	041	031	023	027	030	029	027	028	033	030	033	036	034	035	038	038	038	038	038	038	021
25	038	038	038	038	037	032	023	020	030	025	026	038	045	046	045	045	041	038	039	040	040	040	041	042	028
26	042	042	042	042	039	037	032	029	029	033	028	031	039	041	041	040	038	036	038	039	039	040	040	040	017
27	043	044	043	042	042	038	031	030	032	032	031	036	041	040	040	039	037	035	036	037	037	038	038	039	017
28	040	040	041	042	035	025	014	013	017	029	036	038	039	045	040	037	035	035	035	035	037	038	039	039	033
29	039	040	042	043	038	028	018	008	011	016	020	028	034	038	039	039	035	035	035	036	038	039	039	039	048
30 Q	041	043	043	044	039	027	018	011	016	025	026	031	042	045	043	042	037	036	036	037	038	039	039	039	035
31 Q	040	040	040	042	042	035	021	021	026	034	042	042	042	043	042	041	038	039	039	039	039	039	039	040	024
MEAN	42.6	43.9	44.2	44.3	42.7	36.5	30.2	30.3	32.3	32.9	33.0	38.5	43.6	45.0	44.9	43.0	40.0	40.2	40.8	41.0	41.0	41.3	41.7	42.4	32.5
Q	44.0	44.6	44.6	45.2	42.0	33.0	25.4	23.4	26.4	32.6	35.8	41.2	50.0	50.8	49.2	45.8	41.6	41.8	42.0	43.0	43.2	43.2	43.0	43.6	31.0
D	46.0	47.0	47.2	47.0	45.6	39.6	33.8	33.4	30.6	29.0	32.8	40.8	44.8	42.4	44.2	42.2	40.2	41.6	41.4	41.6	40.6	41.2	42.2	43.2	37.4

VERTICAL COMPONENT OF TERRESTRIAL MAGNETIC FIELD

MEAN VALUES FOR PERIODS OF SIXTY MINUTES
UNCORRECTED FOR NON - CYCLIC VARIATIONS

Z = 600$_{\gamma}$S (0.006 C.G.S. UNIT) + ...

Z 2

FEBRUARY 1960

DATE \ U.T.	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24	RANGE
1	042	042	043	043	039	029	022	017	020	026	031	034	038	038	040	045	042	042	043	043	043	043	044	046	033
2	047	047	047	047	044	035	030	028	029	031	038	046	049	050	048	048	045	042	044	043	042	043	044	046	024
3	047	048	050	051	051	050	050	050	052	051	053	052	049	048	052	050	046	047	045	045	045	047	047	047	012
4	048	048	050	049	046	044	035	038	042	042	044	043	041	044	050	051	046	045	044	043	043	042	045	046	023
5	047	047	046	046	044	041	039	040	043	041	040	039	045	042	046	047	042	041	040	041	039	040	042	044	015
6	045	047	048	047	047	041	037	040	044	046	043	040	042	043	045	045	042	039	041	041	041	042	044	045	015
7 Q	047	047	047	046	045	040	032	032	035	036	038	038	038	040	042	045	041	040	041	042	043	043	044	045	018
8	044	044	044	044	043	040	040	041	044	049	051	048	047	044	043	043	040	041	040	041	042	043	044	045	018
9 Q	045	045	045	043	045	044	047	047	048	052	051	045	042	042	043	042	039	038	038	039	039	040	040	042	016
10 Q	042	043	042	040	034	031	026	026	029	029	028	027	035	037	038	037	035	035	037	035	036	038	039	039	022
11	041	042	041	040	037	034	037	040	041	041	045	046	049	047	044	042	039	039	039	038	038	039	040	043	020
12	044	044	043	042	038	034	030	031	031	036	035	035	037	038	039	040	035	035	037	037	038	040	042	042	018
13	043	043	042	042	042	038	030	025	025	015	019	018	025	031	034	037	035	036	039	039	040	040	040	040	035
14 D	043	043	043	044	045	038	027	023	019	018	019	021	025	028	033	037	038	038	036	038	036	039	040	041	033
15	042	043	043	044	043	036	038	039	042	037	032	037	040	042	043	044	043	042	043	042	045	045	046	043	016
16 D	044	045	046	047	043	038	033	033	031	026	032	037	039	040	043	044	043	043	044	043	043	044	044	045	026
17 D	045	047	047	048	049	050	048	048	050	045	043	043	042	040	044	043	043	041	040	040	039	039	040	042	025
18 D	044	044	043	045	051	051	042	042	037	035	035	036	038	039	039	040	040	041	041	043	044	043	043	044	026
19	045	045	045	044	044	042	041	038	039	037	037	036	040	044	048	048	043	041	042	042	040	042	043	043	019
20	044	045	044	046	047	045	045	045	038	036	036	039	039	040	042	043	041	042	042	042	042	042	042	043	013
21 D	043	043	044	044	043	039	037	035	033	027	024	029	035	035	038	043	040	042	043	043	041	041	043	043	023
22	043	044	044	045	044	041	034	030	032	024	022	029	032	034	037	040	039	039	039	039	038	038	039	040	027
23	041	041	040	043	044	041	033	030	027	028	027	028	034	038	040	041	037	037	038	039	038	037	038	041	021
24 Q	039	040	041	043	045	041	036	035	031	029	029	029	033	036	040	042	039	037	037	038	038	036	037	038	018
25 Q	039	039	040	041	041	035	031	030	031	039	036	038	036	040	040	041	038	037	037	038	038	037	038	039	015
26	039	039	039	042	043	035	026	023	025	031	037	041	042	043	043	041	038	036	036	037	038	037	039	039	024
27	039	039	040	041	033	028	015	009	009	016	023	025	035	038	037	039	036	035	035	037	038	036	036	037	039
28	038	037	037	038	039	033	035	035	035	036	039	034	031	033	037	038	036	035	035	035	035	035	036	036	014
29	038	037	037	036	034	030	028	029	028	029	034	039	041	041	040	038	036	035	035	036	036	035	035	036	019
MEAN	43.0	43.4	43.5	43.8	42.9	38.8	34.6	33.8	34.1	34.1	35.1	36.3	38.6	39.8	41.7	42.6	39.9	39.3	39.7	40.0	39.9	40.2	41.2	42.1	21.7
Q	42.2	42.8	43.0	42.6	42.0	38.2	34.4	34.0	34.8	36.8	36.4	35.2	36.8	39.0	40.6	41.4	38.4	37.4	38.0	38.4	38.8	38.8	39.6	40.6	17.8
D	43.8	44.4	44.6	45.6	46.2	43.2	37.4	36.2	34.0	30.2	30.6	33.2	35.8	36.4	39.4	41.4	40.8	41.0	40.8	41.2	40.8	41.2	42.0	43.0	26.6

VERTICAL COMPONENT OF TERRESTRIAL MAGNETIC FIELD

MEAN VALUES FOR PERIODS OF SIXTY MINUTES
UNCORRECTED FOR NON - CYCLIC VARIATIONS

Z = 600$_{\gamma}$S (0.006 C.G.S. UNIT) + ...

Z 3

MARCH 1960

DATE \ U.T.	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24	RANGE
1	037	037	037	039	037	034	026	021	021	021	015	015	022	027	032	034	031	031	031	030	030	031	032	030	029
2 D	034	034	035	036	035	033	032	024	029	035	037	027	023	026	029	032	031	031	032	032	031	031	031	032	017
3 D	033	033	035	036	035	031	027	026	027	029	032	028	031	034	036	034	033	034	032	033	032	032	034	035	016
4	035	036	037	039	039	039	038	039	043	043	044	046	038	037	038	037	038	037	037	037	035	035	035	037	015
5	037	038	039	041	043	041	038	038	038	041	039	040	041	043	040	039	039	038	039	038	037	037	038	039	011
6	040	041	041	042	037	027	018	009	005	006	009	014	022	027	030	036	038	037	038	038	037	036	037	039	046
7 Q	039	040	040	040	035	028	022	020	026	028	031	029	027	032	037	039	039	038	037	037	037	037	039	039	022
8	040	041	041	041	034	027	021	027	032	037	038	034	035	038	039	038	038	040	041	041	041	041	041	042	026
9	042	042	043	042	038	034	033	034	033	032	038	033	034	035	038	039	040	040	041	042	042	041	043	045	018
10	043	043	043	045	042	036	031	027	030	043	053	049	041	041	039	041	040	041	043	042	043	042	043	043	034
11 D	045	045	045	045	040	038	036	032	036	041	047	049	051	050	048	048	046	043	044	045	043	043	044	047	021
12	048	048	048	048	044	040	034	033	038	041	039	042	044	047	048	048	047	046	047	046	045	045	044	047	020
13 Q	048	048	048	046	042	038	037	038	042	045	048	046	043	046	047	047	047	047	047	047	047	046	047	048	009
14	048	048	049	049	046	045	046	034	034	043	044	040	041	046	048	048	046	044	044	044	044	044	044	044	021
15	045	046	048	048	045	042	036	030	026	030	033	037	036	043	046	045	043	040	040	038	041	040	041	045	026
16 D	046	049	049	052	054	051	040	028	025	034	038	038	037	039	042	042	041	040	042	041	044	043	041	044	041
17	045	045	045	048	043	040	037	032	029	031	040	041	041	041	042	041	041	041	041	039	040	041	041	042	025
18	045	045	045	046	042	031	023	017	018	025	031	033	034	037	040	041	041	041	041	040	040	040	041	041	037
19	043	043	043	047	042	038	035	032	032	040	043	044	039	043	044	044	058	042	042	042	042	042	043	042	021
20 Q	043	043	043	044	040	033	024	020	022	027	032	022	025	030	037	041	041	040	040	041	041	041	041	041	027
21	041	041	042	044	044	040	036	027	026	037	042	036	035	038	041	042	041	041	041	041	042	041	041	042	024
22 Q	043	045	044	045	042	038	039	038	040	045	045	040	035	034	039	042	042	042	041	042	042	042	042	042	016
23 Q	043	044	044	046	042	035	027	024	026	033	039	034	029	031	036	042	042	042	042	042	041	042	042	042	024
24	044	044	043	045	041	036	027	017	017	022	031	029	023	025	034	042	041	041	041	042	042	042	042	043	033
25	043	044	044	045	038	031	022	018	022	028	033	033	033	037	042	043	043	042	043	043	042	042	043	044	032
26	046	046	044	044	043	048*	053*	052	051	054	059	058	053	047	047	050	047	046	044	045	044	044	044	046	025
27	047	048	048	049	047	044	034	034	040	044	048	048	048	051	048	047	047	044	044	042	043	042	044	044	020
28	046	045	047	048	043	035	029	027	032	035	038	046	046	046	045	044	043	042	042	040	038	039	041	042	028
29	042	042	044	044	041	038	033	018	033	042	041	041	039	040	042	042	041	040	039	038	038	037	037	038	036
30	042	042	042	044	040	037	033	023	022	029	030	024	020	025	033	036	037	037	036	035	034	034	036	038	029
31 D	139	041	043	045	045	042	037	033	034	040	036	034	045	043	051	041	039	031	031	028	028	028	026	032	059
MEAN	42.3	42.8	43.2	44.4	44.5	37.1	32.4	27.9	29.8	34.7	37.8	36.6	35.8	37.7	40.2	41.5	41.3	39.9	40.1	39.7	39.5	39.4	39.9	41.2	26.1
Q	43.2	44.0	43.8	44.2	40.2	34.4	29.8	28.0	31.2	35.6	39.0	34.2	31.8	34.6	39.2	42.2	42.2	41.8	41.4	41.8	41.6	41.6	42.2	42.6	19.6
D	39.2	40.4	41.4	42.8	41.8	39.0	34.4	28.6	30.2	35.8	38.0	35.2	37.4	38.4	39.2	39.4	38.0	35.8	36.2	35.8	35.6	35.4	35.2	38.0	30.8

VERTICAL COMPONENT OF TERRESTRIAL MAGNETIC FIELD

MEAN VALUES FOR PERIODS OF SIXTY MINUTES
UNCORRECTED FOR NON - CYCLIC VARIATIONS

$Z = 600_{\gamma}S$ (0.006 C.G.S. UNIT) + ...

Z 4 — APRIL 1960

DATE \ U.T.	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24	RANGE
1 D	041	048	043	035	054	059	049	050	055	064	051	033	025	033	043	046	040	044	041	042	040	036	042	042	078
2	044	043	041	038	059	086	094	090	079	075	072	067	061	054	048	045	044	043	043	042	042	041	041	042	067
3 D	044	047	045	045	043	040	055	059	053	044	043	041	042	046	047	045	044	044	043	042	042	042	042	044	048
4	044	044	045	046	044	037	027	027	032	036	039	040	038	041	043	044	043	042	041	040	040	037	041	040	036
5	040	041	043	048	046	042	030	024	031	025	030	029	027	031	031	031	036	036	036	033	034	034	036	037	049
6	038	038	039	039	038	033	025	019	024	029	035	037	034	032	034	036	036	036	034	034	033	034	034	034	029
7	037	040	041	044	045	037	025	018	018	018	019	019	020	020	022	028	033	032	032	032	038	038	039	040	031
8	041	041	042	036	034	027	019	018	022	030	032	032	031	028	029	033	034	033	033	033	032	032	033	034	024
9 Q	035	036	035	036	036	031	026	027	030	035	037	037	032	028	029	031	034	032	032	031	031	031	032	033	021
10	033	033	035	035	033	031	026	033	043	043	041	039	036	036	036	036	034	032	030	032	032	031	031	033	030
11	037	037	037	037	039	040	040	037	035	035	032	035	037	037	035	034	037	036	034	034	034	035	036	037	014
12	038	039	040	040	037	034	029	031	035	040	039	044	037	035	039	041	040	039	037	037	037	035	037	038	022
13	039	047	043	040	038	036	032	032	031	031	030	031	032	037	040	041	041	039	038	037	038	037	038	039	017
14	042	043	045	047	049	043	032	026	025	024	027	029	031	032	037	039	041	041	040	040	039	038	039	041	033
15	042	043	043	045	044	043																			
16							032	031	033	031	036	034	032	034	039	042	041	041	042	040	039	041	042	045	
17	045	046	047	044	048	055	056	055	049	040	042	041	039	038	041	042	043	041	039	039	039	038	041	042	025
18	043	044	045	042	042	040	036	036	036	031	034	031	032	032	034	038	039	039	038	038	038	038	038	040	020
19 Q	040	040	041	039	042	041	032	026	024	022	018	022	022	021	026	033	036	037	036	036	036	037	035	038	029
20 Q	039	039	039	039	039	036	033	033	030	024	021	025	025	022	025	032	035	035	035	033	034	035	037	037	023
221 Q	037	037	038	037	038	035	033	033	031	026	025	022	025	030	034	041	034	032	031	030	030	030	032	033	016
22 Q	033	034	035	034	032	029	021	021	025	023	025	025	024	025	030	033	033	033	033	033	033	032	032	033	020
23	034	034	035	035	039	036	034	029	021	016	015	024	024	025	028	033	035	033	031	031	032	032	033	032	027
24 D	034	035	036	033	040	039	036	030	032	033	028	025	025	027	029	034	037	035	033	032	033	032	035	035	024
25	036	038	040	034	036	036	036	030	032	032	029	033	035	031	029	035	034	035	034	034	033	036	036	037	023
26	039	041	039	036	047	053	053	048	043	040	034	029	025	023	025	030	035	034	034	034	034	036	037	036	034
27	038	040	040	037	040	045	046	043	042	034	030	031	030	028	029	035	037	035	034	033	032	029	027	028	024
28 D	034	033	038	036	049	048	026	026	017	018	019	023	018	017	026	034	034	030	029	028	029	033	033	033	044
29	035	035	038	036	038	038	030	036	038	031	026	024	026	029	033	035	035	034	033	032	033	033	031	033	027
30 D	037	036	036	045	050	051	042	048	053	046	038	038	034	036	036	032	030	019	022	025	026	027	032	033	060
MEAN	38.6	39.5	40.1	39.2	42.0	41.4	36.4	35.0	35.1	33.7	32.7	32.4	31.0	31.3	33.7	36.2	37.1	35.9	35.1	34.8	34.9	34.8	35.9	36.9	36.0
Q	36.8	37.2	37.6	37.0	37.4	34.4	29.0	28.0	28.0	26.0	25.2	26.6	25.6	25.2	28.8	34.0	34.4	33.8	33.4	32.6	32.8	33.0	33.6	34.8	21.8
D	38.0	39.8	39.6	38.8	47.2	47.4	41.6	42.6	42.0	41.0	35.8	32.0	28.8	31.8	36.2	38.2	37.0	34.4	33.6	33.8	34.0	34.0	36.8	37.4	50.8

VERTICAL COMPONENT OF TERRESTRIAL MAGNETIC FIELD

MEAN VALUES FOR PERIODS OF SIXTY MINUTES
UNCORRECTED FOR NON - CYCLIC VARIATIONS

$Z = 600_{\gamma}S$ (0.006 C.G.S. UNIT) + ...

Z 5 — MAY 1960

DATE \ U.T.	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24	RANGE
1 D	034	035	036	036	037	054	050	048	045	045	034	033	033	033	036	038	038	038	037	036	036	036	038	036	059
2	036	037	040	038	037	037	037	038	040	041	041	037	038	041	042	039	039	038	037	035	034	034	035	037	012
3	037	037	038	038	042	033	027	021	023	019	016	019	020	024	032	035	036	036	035	033	033	033	033	033	028
4 Q	035	037	037	038	039	038	034	029	022	019	015	019	017	017	025	032	035	035	034	034	034	034	035	035	030
5	036	036	038	036	042	042	036	033	035	036	037	035	035	034	038	038	038	037	036	034	033	035	035	035	016
6 D	036	037	037	035	040	037	029	030	030	031	032	037	035	036	034	033	035	034	033	034	033	032	032	035	022
7 D	034	036	038	036	039	049	050	047	046	046	039	042	040	042	039	037	037	034	032	033	035	034	036	037	043
8 D	038	038	037	037	039	042	044	045	028	020	030	026	023	024	032	033	039	035	034	031	031	028	032	033	050
9 Q	039	039	038	040	047	047	049	050	049	045	041	041	041	037	038	039	041	040	040	039	039	038	037	038	029
10	039	040	038	037	034	032	029	029	031	030	028	023	025	027	029	033	036	036	034	034	034	034	034	034	021
11	035	035	034	033	034	037	040	039	038	037	023	020	023	030	032	035	035	034	034	033	033	033	034	036	034
12	037	038	038	039	042	041	040	037	035	033	030	030	033	029	028	035	038	037	035	034	034	034	035	036	022
13	038	039	039	039	045	040	041	037	033	031	026	021	023	028	031	033	035	034	034	034	034	034	034	035	025
14	020	038	038	035	038	039	036	038	039	038	039	037	037	035	034	036	038	037	037	036	035	034	036	036	010
15	036	037	037	037	040	042	045	044	036	032	029	031	035	035	034	036	038	038	038	037	037	037	037	037	(28)
16	038	038	040	042	046	037	033	033	028	026	023	027	025	024	033	033	034	031	031	040	027	028	026	028	035
17	029	031	030	028	036	034	033	034	033	029	024	023	024	024	024	029	034	034	034	033	033	033	032	032	022
18 Q	032	032	033	032	038	040	043	037	033	027	025	027	027	032	033	034	036	036	034	034	035	034	034	034	022
19 Q	034	034	033	033	041	045	047	045	042	038	033	033	040	029	029	034	037	037	038	038	038	037	037	037	022
20 Q	037	036	036	037	039	041	037	026	019	018	022	023	021	023	028	036	038	037	036	036	036	037	038	038	026
21	038	038	037	036	040	048	043	037	032	030	021	022	026	027	030	035	039	038	038	037	037	037	038	038	031
22 Q	039	039	038	039	050	057	054	046	038	033	031	030	028	027	030	035	037	035	034	035	034	035	037	038	032
23	039	037	037	035	039	039	040	041	042	040	032	027	026	024	031	038	036	034	033	033	033	035	036	(036)	022
24							033	041	034	033	024	017	020	027	029	033	035	034	032	031	034	034	034	034	
25	034	035	035	033	033	031	032	030	029	026	022	022	027	031	033	035	036	034	033	034	034	035	035	035	020
26							047	043	040	045	039	033	028	026	032	034	034	034	034	034	034	034	034	034	
27	034	036	038	037	042	045	043	041	035	029	024	027	026	025											
28										022	022	025	026	029	031	034	036	037	036	035	034	035	035	033	
29 D	033	038	042	042	044	045	044	035	031	029	021	015	014	016	021	028	034	034	034	034	033	033	035	035	063
30	035	035	034	030	035	040	044	048	046	047	042	034	028	027	028	033	038	039	039	038	037	038	038	037	027
31	038	038	036	035	044	053	058	052	050	044	043	038	037	036	036	035	037	035	035	034	033	033	035	035	030
MEAN	35.3	36.6	36.9	36.2	40.1	41.6	40.6	38.5	36.1	32.9	32.5	28.2	28.4	29.0	31.7	34.6	36.6	35.7	35.0	34.8	34.2	34.3	34.9	35.2	28.9
Q	35.4	35.6	35.4	35.8	41.2	44.2	43.0	36.6	30.8	27.0	25.2	26.4	26.6	25.6	29.0	34.2	36.6	36.0	35.2	35.4	35.4	35.4	36.2	36.4	26.4
D	35.0	36.8	38.0	37.2	39.8	45.4	43.4	41.0	36.0	34.2	31.2	30.6	29.0	30.2	32.4	33.8	36.6	35.0	34.0	33.6	36.6	32.6	34.6	35.2	47.4

VERTICAL COMPONENT OF TERRESTRIAL MAGNETIC FIELD

MEAN VALUES FOR PERIODS OF SIXTY MINUTES
UNCORRECTED FOR NON - CYCLIC VARIATIONS

$Z = 600_{\gamma}S$ (0.006 C.G.S. UNIT) + ...

Z 6

JUNE 1960

DATE \ U.T.	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24	RANGE
1	035	037	037	034	039	038	039	037	030	011	007	000	013	022	028	034	036	034	033	033	031	032	033	033	049
2 Q	034	035	036	036	040	039	035	036	032	032	032	033	033	032	031	032	035	034	033	032	032	032	032	032	012
3	034	034	034	032	035	037	035	034	030	027	021	023	027	032	031	032	033	031	030	029	028	027	030	031	020
4 D	033	033	033	032	038	048	044	039	042	031	028	021	027	029	031	032	031	029	028	027	027	028	027	029	041
5	029	030	033	033	039	045	057	045	040	037	032	031	030	030	036	038	038	037	036	034	036	034	034	034	042
6	035	036	038	042	047	046	041	035	036	028	020	018	020	021	027	031	034	032	031	031	031	031	033	034	033
7	034	035	036	033	038	041	039	033	029	031	029	032	026	024	028	033	036	035	033	033	035	035	035	036	020
8	037	037	036	034	040	038	032	024	020	025	018	013	014	016	023	033	036	035	034	034	035	035	035	036	034
9	036	036	035	031	035	042	043	044	042	043	043	044	036	037	037	036	036	036	035	037	037	037	037	037	019
10 Q	039	036	036	035	036	038	041	044	043	048	046	038	032	030	028	033	037	037	036	036	036	036	036	036	022
11 Q	036	036	036	034	038	041	042	042	043	049	050	041	036	030	030	033	036	036	036	035	036	036	037	037	023
12 Q	037	037	036	033	036	043	055	045	032	028	025	024	022	026	030	034	038	037	036	036	036	037	037	038	043
13	038	039	039	038	042	047	046	032	031	037	033	031	036	041	041	039	041	040	038	037	037	037	038	039	019
14	039	041	039	039	044	044	046	050	049	041	034	033	030	033	036	036	041	041	040	039	040	041	041	041	024
15	042	042	042	041	044	052	054	051	047	046	047	045	042	038	037	039	043	042	042	041	042	042	042	042	020
16 Q	042	042	042	037	037	040	047	045	040	030	021	025	032	037	041	042	043	044	043	042	042	042	042	043	032
17	043	045	045	043	043	044	050	051	049	047	043	042	040	038	038	041	042	042	042	042	042	042	042	042	015
18	043	042	042	038	040	044	041	036	029	026	029	037	042	046	046	046	046	044	043	040	041	041	042	042	024
19	043	044	043	042	045	047	032	036	042	045	045	037	031	033	033	037	040	038	037	036	036	037	037	037	022
20	037	037	037	035	039	043	050	050	045	043	037	033	031	034	036	037	038	039	038	037	037	037	037	037	022
21	038	039	037	036	041	047	045	040	039	034	028	035	040	038	038	040	040	037	037	037	037	037	037	038	029
22	039	041	042	041	043	044	047	042	039	039	037	034	032	031	031	036	038	038	038	037	036	036	037	037	020
23	038	038	041	036	036	044	049	046	039	037	030	031	033	033	036	038	038	038	037	037	037	038	038	038	023
24	041	040	040	038	041	050	053	051	048	043	036	038	036	038	039	040	041	041	039	037	040	038	038	040	070
25	041	041	041	038	041	046	050	044	037	041	037	037	038	035	033	036	037	037	037	036	036	037	038	038	019
26	041	041	044	045	048	047	049	047	043	042	039	039	036	035	033	037	041	040	038	038	038	038	038	039	020
27 D	040	038	043	047	055	057	057	041	029	022	024	027	029	032	034	038	039	038	035	034	035	034	036	037	055
28 D	038	039	041	040	047	047	057	059	053	050	036	034	035	031	033	037	041	039	038	037	038	038	038	039	059
29 D	041	042	041	037	036	040	047	053	057	047	040	039	036	038	038	039	041	042	041	040	038	036	035	036	032
30 D	036	038	044	047	056	065	063	062	051	045	044	041	040	038	038	039	040	038	039	038	037	037	040	040	036
MEAN	38.0	38.4	39.0	37.6	41.3	44.8	46.2	43.1	39.5	36.8	33.0	31.9	31.8	32.6	34.0	36.6	38.5	37.7	36.8	36.1	36.3	36.3	36.7	37.3	30.2
Q	37.6	37.2	37.2	35.0	37.4	40.2	44.0	42.4	38.0	37.4	34.8	32.2	30.8	31.0	32.0	34.8	37.8	37.6	36.8	36.2	36.4	36.6	36.8	37.2	26.4
D	37.6	38.0	40.4	40.6	46.4	51.4	53.6	50.8	46.4	39.0	34.4	32.4	33.4	33.6	34.8	37.0	38.4	37.2	36.2	35.2	34.6	34.6	35.2	36.2	44.6

DAILY MEANS AND EXTREMES OF HORIZONTAL COMPONENT

$H = 36{,}000_{\gamma}$ (0.36 C.G.S. UNIT) + ...

1960 DATE		JANUARY Max	Min	Mean	Ci		FEBRUARY Max	Min	Mean	Ci		MARCH Max	Min	Mean · Ci	
1	Q	228	079	120	0.0		271	072	122	0.4		262	047	116	1.1
2	Q	248	057	114	0.1		259	-42	95	1.1	D	230	045	102	1.1
3		257	073	121	0.1		206	003	69	1.0	D	211	050	92	1.1
4		231	079	118	0.6		182	032	86	0.9		177	026	92	1.1
5		204	026	88	1.1		267	021	95	1.1		162	059	103	0.9
6		176	040	91	0.5		197	046	96	0.9		275	081	131	0.8
7		197	058	111	0.2	Q	210	072	121	0.2	Q	270	056	132	0.1
8		209	084	130	0.2		215	072	121	0.6		230	082	130	0.8
9	Q	239	094	137	0.1	Q	187	080	128	0.2		264	044	119	0.7
10	D	326	058	88	1.6	Q	233	107	143	0.1		244	016	105	1.1
11	D	172	024	65	1.2		249	061	132	0.4	D	230	049	102	1.3
12		181	059	87	1.0		207	072	127	0.2		234	070	110	0.3
13		222	051	97	0.8		271	-2	130	0.8	Q	248	078	124	0.1
14	D	348	-55	74	1.6	D	164	016	74	1.2		291	001	137	0.4
15	D	146	-37	38	1.2		157	057	86	0.6		180	-49	117	1.2
16		176	032	78	0.5	D	256	027	105	1.3	D	214	040	49	1.6
17		223	049	116	0.9	D	196	029	93	1.2		258	056	95	1.1
18		316	005	112	1.2	D	198	016	83	1.1		261	073	121	0.6
19		207	058	108	0.5		222	020	105	1.2		230	090	127	0.5
20		277	054	113	1.1		166	025	93	0.9	Q	229	089	135	0.0
21	D	238	-3	85	1.7	D	216	066	110	1.1		221	095	136	0.4
22		185	026	74	1.1		198	069	118	0.4	Q	260	096	139	0.2
23		228	049	46	1.0		219	077	124	0.4	Q	270	080	154	0.2
24		185	046	89	0.9	Q	202	065	121	0.1		290	080	144	0.9
25		213	068	111	0.6	Q	283	077	141	0.2		285	094	141	0.3
26		220	070	112	0.2		242	090	140	0.2		290	097	139	0.3
27		194	069	108	0.3		273	067	136	1.1		290	104	149	0.2
28		272	072	124	0.2		237	086	133	0.2		300	053	131	1.0
29		327	090	136	0.7		267	056	125	0.9		340	061	123	1.0
30	Q	324	081	145	0.0							320	005	124	1.1
31	Q	286	089	138	0.1						D	253	-219	45	2.0
MEAN				104	0.69				112	0.69				118	0.76
DAYS				31	31				29	29				31	31

1960 DATE		APRIL Max	Min	Mean	Ci		MAY Max	Min	Mean	Ci		JUNE Max	Min	Mean	Ci
1	D	289	-372	-144	2.0	D	116	101	-17	1.4		290	057	104	1.2
2		056	-163	-47	1.5		215	-11	67	0.7	Q	199	047	120	0.2
3	D	149	-58	25	1.5		176	039	89	0.3		198	079	136	0.6
4		194	-58	66	1.1	Q	190	174	101	0.2	D	159	008	99	1.5
5		260	-30	83	1.2		214	063	112	0.5		151	002	75	1.3
6		199	038	94	0.9	D	198	-54	71	1.6		194	037	117	1.2
7		197	-16	87	0.9	D	265	001	72	1.5		239	070	132	0.8
8		217	046	88	0.9	D	275	144	39	1.9		199	053	118	1.1
9	Q	238	048	102	0.7		206	030	72	1.0		216	065	129	1.0
10		262	003	108	1.2		180	046	90	0.7	Q	200	064	134	0.2
11		196	029	82	1.0		245	045	97	1.3	Q	164	063	147	0.2
12		213	036	79	1.2		230	055	95	1.0	Q	307	104	166	0.2
13		216	046	90	1.0		258	067	115	0.7		271	116	155	0.2
14		204	046	90	0.8		252	057	112	0.7		261	073	136	0.8
15							238	076	111	0.6		261	064	120	0.4
16		254	-34		1.2		264	048	137	1.3	Q	238	093	140	0.1
17		210	031	83	1.1		269	075	123	0.9		206	096	137	0.2
18		208	040	95	1.0	Q	185	089	118	0.2		247	104	143	0.8
19	Q	207	069	115	0.1	Q	225	091	122	0.2		157	073	104	0.8
20	Q	223	067	118	0.0	Q	213	093	124	0.1		180	089	116	0.4
21	Q	224	078	130	0.1		226	086	127	0.2		185	062	104	0.8
22	Q	227	095	129	0.2	Q	199	095	130	0.3		190	077	117	0.7
23		255	-3	134	0.8		203	065	127	1.1		209	079	123	0.7
24	D	155	-66	25	1.6		142	014		1.2		205	076	124	0.9
25		208	-28	42	1.4		195	050	89	1.1		229	053	118	1.2
26		187	007	65	1.0		186	061		1.1		186	061	111	1.2
27		178	-15	74	1.3		216			0.9	D	205	-31	92	1.6
28	D	163	-96	-1	1.7		189	084		0.9	D	191	037	98	1.3
29		126	009	45	1.4	D	228	025	109	1.6	D	246	042	116	1.4
30	D	303	-514	-47	2.0		191	044	96	1.1	D	174	-87	78	1.6
31							248	067	128	0.9					
MEAN				65	1.07				98	0.88				120	0.82
DAYS				28	30				27	31				30	30

DAILY MEANS AND EXTREMES IN DECLINATION

D = −00° + ... (IN TENTHS OF A MINUTE)

1960	JANUARY				FEBRUARY				MARCH				APRIL				MAY				JUNE			
DATE	Max	Min	Mean	Ci	Max	Min	Mean	Ci	Max	Min	Mean	Ci	Max	Min	Mean	Ci	Max	Min	Mean	Ci	Max	Min	Mean	Ci
1	Q 450	391	415	0.0	477	427	444	0.4	448	430	437	1.1	D 450	347	365	2.0	D 417	359	384	1.4	430	392	410	1.2
2	Q 450	401	420	0.1	457	418	437	1.1	D 444	429	432	1.1	416	319	383	1.5	404	374	389	0.7	Q 428	410	417	0.2
3	441	402	418	0.1	455	425	438	1.0	D 437	414	428	1.1	D 407	356	385	1.5	421	385	404	0.3	435	405	417	0.6
4	432	412	419	0.6	457	423	438	0.9	458	429	436	1.1	405	375	387	1.1	Q 418	398	406	0.2	D 439	399	415	1.5
5	433	394	409	1.1	467	428	442	1.1	441	426	432	0.9	428	383	401	1.2	413	397	406	0.5	423	406	413	1.3
6	454	405	421	0.5	457	428	439	0.9	458	424	434	0.8	411	389	396	0.9	D 425	393	406	1.6	435	401	417	1.2
7	430	406	419	0.2	Q 464	431	445	0.2	Q 445	416	433	0.1	418	372	397	0.9	D 431	377	397	1.5	437	398	418	0.8
8	447	410	424	0.2	465	428	443	0.6	452	418	431	0.8	405	380	393	0.9	D 437	383	401	1.9	435	403	417	1.1
9	Q 433	408	421	0.1	Q 459	440	447	0.2	445	421	431	0.7	Q 412	395	402	0.7	432	382	402	1.0	433	377	414	1.0
10	D 463	400	418	1.6	Q 468	438	447	0.1	448	416	427	1.1	413	382	396	1.2	425	400	406	0.7	Q 432	391	414	0.2
11	D 439	410	421	1.2	459	433	444	0.4	D 444	409	422	1.3	425	389	403	1.0	431	396	407	1.3	Q 435	400	418	0.2
12	474	413	428	1.0	468	426	446	0.2	437	406	420	0.3	422	397	400	1.2	422	390	405	1.0	Q 442	398	421	0.2
13	444	389	418	0.8	486	424	446	0.8	Q 432	400	419	0.1	412	382	397	1.0	439	405	412	0.7	431	398	419	0.2
14	D 467	389	426	1.6	D 470	435	444	1.2	438	406	422	0.4	416	399	403	0.8	429	385	411	0.7	433	405	420	0.8
15	D 470	404	428	1.2	457	425	440	0.6	438	397	415	1.2					431	406	414	0.6	427	407	415	0.4
16	442	406	425	0.5	D 452	428	440	1.3	D 429	393	407	1.6					458	408	421	1.3	Q 423	391	410	0.1
17	456	407	426	0.9	D 466	428	443	1.2	435	411	417	1.1	427	384	402	1.1	454	402	418	0.9	426	402	415	0.2
18	469	401	434	1.2	D 456	427	435	1.1	429	395	413	0.6	416	397	402	1.0	Q 427	408	415	0.2	435	390	415	0.8
19	447	412	431	0.5	451	427	436	1.2	431	389	412	0.5	Q 423	397	406	0.1	Q 445	392	419	0.2	418	395	406	0.8
20	468	431	441	1.1	447	429	436	0.9	Q 433	401	416	0.0	Q 414	394	404	0.0	Q 442	402	421	0.1	425	391	411	0.4
21	D 461	402	429	1.7	D 461	418	438	1.1	426	403	415	0.4	Q 420	395	406	0.1	436	403	418	0.2	433	384	409	0.8
22	451	420	430	1.1	463	420	436	0.4	Q 429	410	416	0.2	Q 414	384	405	0.2	Q 436	423	422	0.3	428	380	407	0.7
23	447	405	427	1.0	465	426	440	0.4	Q 426	329	415	0.2	418	395	406	0.8	448	405	420	1.1	434	374	408	0.7
24	450	408	433	0.9	Q 462	430	444	0.1	431	402	414	0.9	D 410	360	386	1.6	425	402		1.2	421	385	404	0.9
25	451	409	434	0.6	Q 452	425	441	0.2	422	399	412	0.3	415	382	394	1.4	424	398	408	1.1	436	388	406	1.2
26	460	430	443	0.2	456	417	441	0.2	420	391	408	0.3	421	384	400	1.0	430	402		1.1	433	379	403	1.2
27	461	424	442	0.3	455	402	432	1.1	417	397	412	0.2	415	377	401	1.3	455			0.9	D 411	359	394	1.6
28	473	417	443	0.2	464	433	445	0.2	419	390	407	1.0	D 419	353	386	1.7	434	400		0.9	D 425	380	398	1.3
29	486	419	444	0.7	445	419	435	0.9	417	397	404	1.0	404	389	394	1.4	D 442	396	415	1.6	D 423	366	394	1.4
30	Q 486	409	443	0.0					418	394	402	1.1	D 467	361	384	2.0	438	393	413	1.1	D 414	373	392	1.6
31	Q 477	422	445	0.1					D 453	339	395	2.0					438	396	420	0.9				
MEAN			428	0.69			441	0.69			419	0.76			396	1.07			410	0.88			410	0.82
DAYS			31	31			29	29			31	31			28	30			28	31			30	30

DAILY MEANS AND EXTREMES OF VERTICAL COMPONENT

Z = 600γ S (0.006 C.G.S. UNIT) + ...

1960	JANUARY				FEBRUARY				MARCH				APRIL				MAY				JUNE			
DATE	Max	Min	Mean	Ci	Max	Min	Mean	Ci	Max	Min	Mean	Ci	Max	Min	Mean	Ci	Max	Min	Mean	Ci	Max	Min	Mean	Ci
1	Q 054	016	041	0.0	047	014	037	0.4	040	011	029	1.1	D 085	007	044	2.0	D 078	019	038	1.4	047	-02	029	1.2
2	Q 064	030	047	0.1	051	027	042	1.1	D 037	020	031	1.1	102	035	056	1.5	043	031	038	0.7	Q 041	029	034	0.2
3	051	020	041	0.1	056	044	049	1.0	D 038	022	032	1.1	D 066	018	045	1.5	043	015	031	0.3	039	019	031	0.6
4	064	040	052	0.6	054	031	045	0.9	048	033	038	1.1	057	021	040	1.1	Q 041	011	030	0.2	D 060	019	032	1.5
5	052	023	045	1.1	049	034	043	1.1	045	034	039	0.9	065	016	035	1.2	046	030	036	0.5	069	027	036	1.3
6	060	008	039	0.5	050	035	043	0.9	045	-01	029	0.8	042	013	034	0.9	D 047	025	034	1.6	049	016	032	1.2
7	052	037	045	0.2	Q 048	030	041	0.2	Q 041	019	034	0.1	047	016	031	1.1	D 065	022	039	1.5	042	022	033	0.8
8	051	025	039	0.2	056	038	044	0.6	043	017	036	0.8	041	017	032	0.9	D 056	006	033	1.9	045	011	030	1.1
9	Q 055	031	042	0.1	Q 053	037	043	0.2	045	027	039	0.7	Q 041	020	032	0.7	Q 059	030	041	1.0	047	028	038	1.0
10	D 056	016	041	1.6	Q 044	022	035	0.1	056	022	041	0.1	048	018	034	1.2	041	020	033	0.7	Q 050	028	037	0.2
11	D 056	031	045	1.2	052	032	040	0.4	D 053	032	044	1.3	043	029	036	1.0	049	015	033	1.3	Q 052	029	038	0.2
12	060	030	045	1.0	045	027	038	0.2	050	030	044	1.3	049	027	037	1.2	048	026	035	1.0	Q 064	021	035	0.2
13	068	032	047	0.8	045	010	034	0.8	Q 046	037	045	0.1	043	026	037	1.0	045	020	034	0.7	048	029	038	0.2
14	D 053	-08	039	1.6	D 047	014	034	1.2	050	029	044	0.4	052	019	037	0.8	042	032	036	0.7	052	028	040	0.8
15	D 060	036	047	1.2	046	030	041	0.6	049	023	040	1.2				1.0	053*	025	037	0.6	056	036	044	0.4
16	056	031	044	0.5	D 048	022	040	1.3	D 060	019	042	1.6				1.2	047	012	032	1.3	Q 051	019	039	0.1
17	048	013	038	0.9	D 061	036	044	1.2	049	024	040	1.1	059	034	044	1.1	039	017	030	0.9	052	037	043	0.2
18	067	014	042	1.2	D 056	030	042	1.1	049	012	037	0.6	046	026	038	1.0	Q 046	024	033	0.2	047	023	040	0.8
19	044	019	037	0.5	050	031	042	1.2	050	029	042	0.5	Q 046	017	033	0.1	Q 050	028	037	0.2	051	029	039	0.8
20	057	020	039	1.1	048	035	042	0.9	Q 046	019	036	0.0	Q 042	019	033	0.0	Q 042	016	032	0.1	051	029	039	0.4
21	D 044	007	031	1.7	D 045	022	039	1.1	046	022	039	0.4	Q 039	023	032	0.1	051	020	035	0.2	053	024	038	0.8
22	050	020	033	1.1	046	019	037	0.4	Q 048	032	041	0.2	Q 037	017	030	0.2	Q 058	026	038	0.3	050	030	038	0.7
23	052	-01	033	1.0	046	025	037	0.4	Q 047	023	038	0.2	042	015	030	0.8	045	023	035	1.1	051	028	038	0.7
24	041	020	034	0.9	Q 046	028	037	0.1	047	014	036	0.9	D 045	021	033	1.6		015		1.2	103	033	041	0.9
25	047	019	037	0.6	Q 042	027	038	0.1	048	016	037	0.3	042	019	034	1.4	040	020	032	1.1	051	032	039	1.2
26	043	026	037	0.2	046	022	037	0.2	066	041	048	0.3	055	021	037	1.0				1.1	053	033	041	1.2
27	045	028	038	0.3	043	004	032	1.1	052	032	045	0.2	047	023	035	1.3				0.9	D 073	018	038	1.6
28	043	010	034	0.2	043	029	036	0.2	052	024	041	1.0	D 054	010	030	1.7				0.9	D 083	024	041	1.3
29	046	-02	032	0.7	043	024	035	0.9	048	012	039	1.0	046	019	033	1.4	D 070	007	032	1.6	D 064	032	041	1.4
30	Q 045	010	035	0.0					047	018	034	1.1	D 057	-03	036	2.0	052	025	037	1.1	D 069	033	044	1.6
31	Q 042	018	038	0.1					D 069	010	037	2.0					060	030	040	0.9				
MEAN			040	0.69			040	0.69			039	076			037	1.07			038	0.88			038	0.82
DAYS			31	31			29	29			31	31			29	29			27	27			30	30

THE ETHIOPIAN RIFT SYSTEM

PAUL A. MOHR

Abstract

A descriptive account of the Ethiopian Rift System includes much new information based on field observations, air flights, and aerial photography. Of the individual units of the Ethiopian Rift System, the Main Ethiopian Rift and Afar receive especially detailed study, and Afar is discussed in relation to the three trends of faulting which converge on it, and is shown to be down-warped as well as down-faulted. The faulting of the Ethiopian Rift System is indicated as being intimately, though not coincidentally, related to the preceding uplift of the Arabo-Ethiopian Swell. The age of the faulting is also discussed. Some of the more interesting Quaternary tectonic and volcanic features of the Rift System are listed.

Contents

I. Regional Setting

The Ethiopian Rift System forms a part of the complex tectonic feature termed, briefly, the Rift System, a system of downfaulted troughs extending from Mozambique in the south, northwards through East Africa, the Horn of Africa, the Red Sea, and into Israel, Jordan and Syria. This remarkable feature of the Earth's Crust is thus observed to extend for about 5000Km in a generally north-south direction. When studied in detail the Rift System is found to be composed of a number of non-continuous, though related units (map 1). Of these units, that which comprises the Ethiopian section of the Rift System is of especial interest and importance in that it is here that three major rift units converge and meet; these are:

1. The Main Ethiopian Rift, extending northwards from the Gregory Rift of Kenya in a N.N.E.-S.S.W. direction, and separating the original Arabo-Ethiopian Swell between the Ethiopian and Somalian Plateaux.
2. The Gulf of Aden Rift, trending E.N.E.-W.S.W., and separating the original Arabo-Ethiopian Swell between southern Arabia and the eastern Horn.
3. The Red Sea Rift, trending N.W.-S.E., and separating the original Arabo-Ethiopian Swell between western Arabia and the northern Ethiopian-Sudan Plateau.

These three units of rifting, intimately related to the Arabo-Ethiopian Swell, meet in the Ethiopian region to form the sunken region of Afar, a vast triangular-shaped depression of about 150,000 sq.km., much of which lies below sea-level. The western boundary of Afar is formed by the N.-S. scarp of the Ethiopian Plateau, the southern boundary by the generally E.N.E.-W.S.W. scarp of the Somalian Plateau, and the north-eastern boundary by the Danakil Alps horst whose major scarp faces south-west. These three bounds to Afar are determined by the complex association of faulting of the three trends listed above.

II. Physiography

The comparatively late date of the uplift of the Arabo-Ethiopian Swell and its subsequent dissection by the Rift System faulting signifies that Ethiopian physiography is, on the large scale, chiefly determined by these two tectonic phenomena. That the rifting was related to, though not coincident with, the ridges of maximum uplift and elevation of the Swell is indicated today by the fact that most of the highest summits of the Ethiopian and Somalian Plateaux lie close to the margins of the Rift System, and that all the major rivers of the Plateaux drain away from the Rift System.

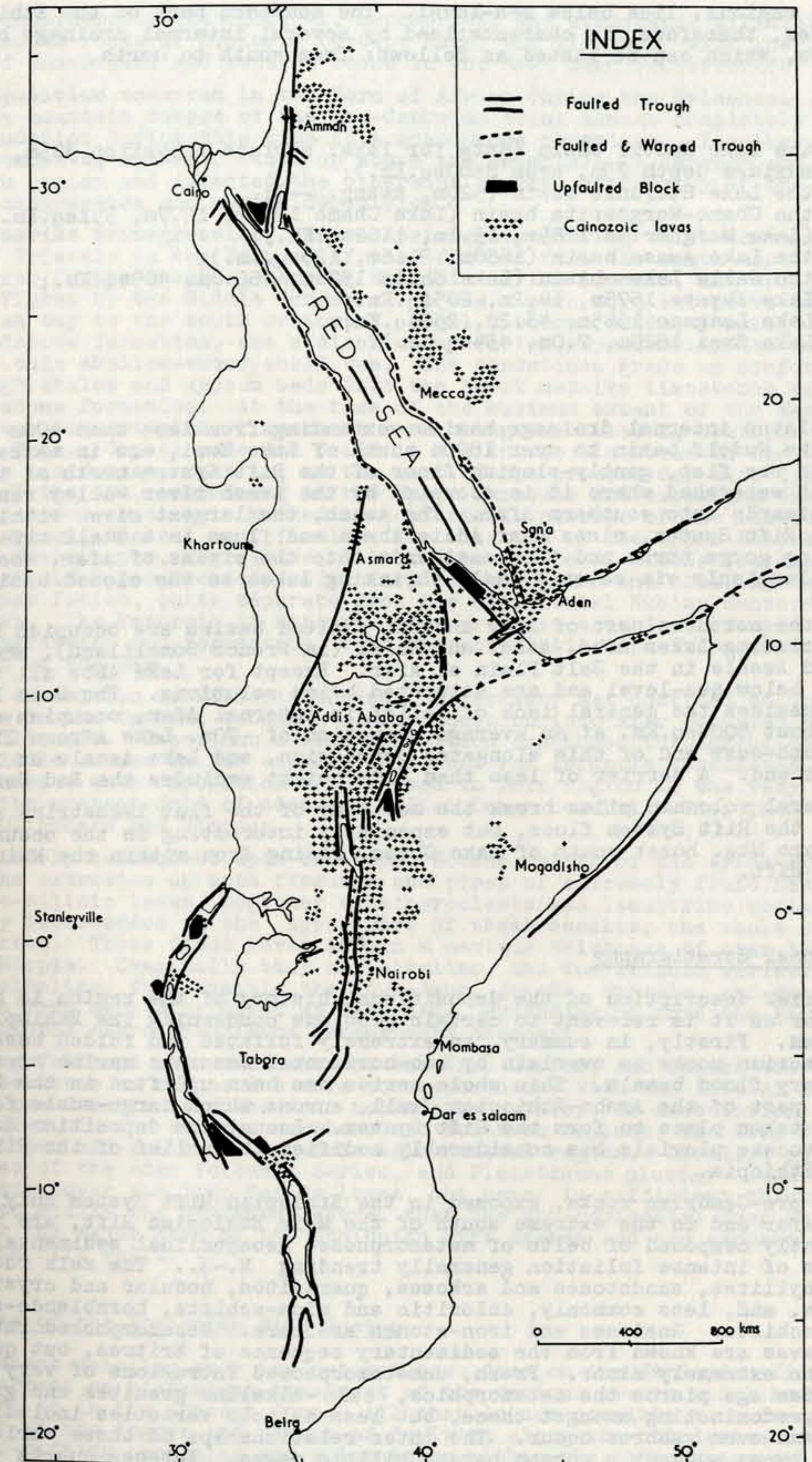
Along the eastern margin of the Ethiopian Plateau the following notable summits occur: Mt. Swera (3013m) in Eritrea, Mts. Asimba (3248m), Adgu (3845m) and Amba Alaji (3439m) in Tigrai, Mts. Sarenga (3658m), Santara (3200m) and Abuya Mieda (4000m) in Wallo, Mts. Jib Washa (3124m), Meghezez (3511m) and other peaks above 3500m north of Addis Ababa, in Shoa, Mt. Guraghe (3719m) in Arussi, and Mt. Gughe (3800m) in Gamu-Gofa. From these and from numerous lesser heights of the Ethiopian Plateau huge horsts, usually stepped and now deeply denuded, overlook the Rift System to the east, the total change of elevation sometimes exceeding 4000m. Owing to denudation this change of elevation is usually extended over a horizontal distance of 15 to 25Km. through 'badland' regions.

Along the western and northern margins of the Somalian Plateau the following notable summits occur: Mts. Delo (3600m) and Garamba (3327m) in Sidamo, Mts. Kakka (4190m), Badda (4133m) and Gugu (3532m) in Arussi, Mts. Tita (3122m) and Mullata (3381m) in Hararge, and thence eastwards via Mt. Shimber Berris (2408m) in Somaliland to Cape Guardafui.

The Danakil Alps horst, differing from the two Plateaux in that it does not represent the original elevation of the Arabo-Ethiopian Swell in that region, reaches heights of merely 1340m in the north-west and 2130m south of Ed.

Evidence will be presented below to suggest that only very rarely do physiographic scarp features coincide with rift-boundary faults in the Ethiopian Rift System, owing to the considerable degree of denudation which has occurred since rifting took place. On the Rift System floor, however, the preservation of fresh fault-scarps is a common phenomenon.

The Ethiopian Rift System floor rises in rather irregular profile from the Lake Rudolf basin up to the main watershed north of Lake Zwai, and then descends northwards in monotonously regular fashion into Afar where the floor, over



Map 1. Relationship of the Ethiopian Rift System to the Rift System proper.

extensive regions, lies below sea-level. The southern part of the Ethiopian Rift System, therefore, is characterised by several internal drainage basins with lakes, which can be listed as follows: from south to north,

the Lake Rudolf basin (data for lake: surface elevation 375m, maximum depth 73m, area 8600sq.Km.);
the Lake Stefanie basin (520m, swamp, --);
the Chamo-Margherita basin (Lake Chamo 1230m, 12.7m, 551sq.Km.) (Lake Margherita 1285m, 13.1m, 1162sq.Km.);
the Lake Awasa basin (1680m, 21.6m, 129sq.Km.);
the Galla Lakes basin (Lake Shala 1570m, 266.0m, 409sq.Km.; Lake Abyata 1575m, 14.2m, 205sq.Km.; Lake Langano 1585m, 46.2m, 230sq.Km; Lake Zwai 1625m, 7.0m, 434sq.Km.).

These isolated internal drainage basins, extending from less than 400m elevation in the Lake Rudolf basin to over 1800m north of Lake Zwai, are in marked contrast with the flat, gently-sloping floor of the Rift System north of the Maki-Awash watershed where it is occupied by the Awash river valley running north-eastwards into southern Afar. The Awash, the largest river within the Ethiopian Rift System, rises near Addis Ababa and flows in a small ziz-zagging and winding gorge north and then eastwards onto the plains of Afar, whence it extends sluggishly via several small shrinking lakes to the closed basin of Lake Abbe.

In the northern part of Afar several faulted basins are occupied by lakes, including Lakes Abbe, Assal and Halol (in French Somaliland), and Afrera and Assale in the Salt Plain of Afar. Except for Lake Abbe all these lakes lie below sea-level and are saturated brine solutions. The Salt Plain which emphasises the general lack of relief in internal Afar, occupies an area of about 8000sq.Km. at an average elevation of -70m. Lake Afrera lies at the south-east end of this elongated depression, and Lake Assale at its north-west end. A barrier of less than 200m height excludes the Red Sea.

Several volcanic piles break the monotony of the flat lacustrine sediments of the Rift System floor, but especially interesting is the occurrence of the Amaro Mts. horst south of Lake Chamo, rising from within the Main Ethiopian Rift.

III. Regional Stratigraphy

A brief description of the depositional history of the region is given here as far as it is relevant to certain problems concerning the Ethiopian Rift System. Firstly, in summary, an extremely foliated and folded basement of pre-Cambrian rocks is overlain by sub-horizontal Mesozoic marine strata and Tertiary flood basalt. This whole series has been uplifted in the Upper Eocene as part of the Arabo-Ethiopian Swell, across which large-scale faulting has later taken place to form the Rift System. Lacustrine deposition during the Pleistocene pluvials has considerably modified the relief of the Rift floor in Ethiopia.

The pre-Cambrian rocks, exposed in the Ethiopian Rift System only in northern Afar and in the extreme south of the Main Ethiopian Rift, are very predominantly composed of belts of metamorphosed geosynclinal sediments, with the planes of intense foliation generally trending N.-S.. The main rock-types include phyllites, sandstones and arkoses, quartzites, nodular and crystalline limestones, and, less commonly, chloritic and mica-schists, hornblende-schists and talc-schists. Gneisses and iron-stones are rare. Metamorphosed interbedded silicic lavas are known from the sedimentary sequence of Eritrea, but quantitatively are extremely minor. Fresh, unmetamorphosed intrusions of very late pre-Cambrian age pierce the metamorphics, calc-alkaline granites and granodiorites predominating amongst these, but less silicic varieties including diorites and even gabbros occur. The inter-relationships of these various intrusive types suggest a common parent silicic magma. Intense quartz vein injection was the last igneous manifestation of the pre-Cambrian in Ethiopia, these veins generally being rich in iron-ore minerals and frequently auriferous

There is a considerable lithological, metamorphic and structural affinity of the pre-Cambrian rocks of Ethiopia (except Harar and Ilubabor) with the Inda Ad series of Somaliland and related rocks in the East Aden Protectorate.

No deposition occurred in the Horn of Africa during the Palaeozoic, the orogenic mountain ranges of the pre-Cambrian being almost completely worn down by denudation during this time to a monotonous peneplain. Inselbergs and other remnants, however, stood up above the peneplain in Hararge and the Danakil Alps region and affected the otherwise general uniformity of the Mesozoic transgression and marine deposition.

This marine transgression, due to epeirogenic sinking which commenced in the late Triassic in the Horn of Africa, flooded from the south-east to reach Harar in the Rhaetic, central Ethiopia in the Liassic, and Wollega, Gojjam and Tigrai by the Middle Jurassic; it was a much more extensive transgression than any to the south or north. Basal littoral sands, forming the Adigrat Sandstone formation, are a diachronous facies representing the first deposits of this shallow-water shelf sea. The sandstones grade up conformably through shales and gypsum beds into the thick massive limestones of the Antalo Limestone formation. At the time of the maximum extent of the Mesozoic sea, the Lower Kimmeridgian, limestones were being deposited in southern Tigrai and Western Shoa. Cephalopods are found in the Antalo Limestone in the Danakil Alps, Harage and Borana, that is, to the east of the present-day Rift System. Regression of the sea, commencing in the Upper Jurassic and extending throughout the Cretaceous, was again marked by conformable passage of the limestones up through gypsum, shales, and, finally, the clastics of the Upper Sandstone formation. These upper, regressive, littoral sands are of Middle Cretaceous age in Arussi and Upper Cretaceous-Tertiary in the Ogaden and Somalia; they are a distinct facies, quite separate from the continental Nubian Sandstone of N.E. Sudan. The Mesozoic in Ethiopia thus provides a perfect example of a marine transgression and regression, with characteristic deposition according to the depth of the sea.

Marine deposition in Ethiopia during the Tertiary was confined to the Lower Eocene in the Ogaden, though a minor incursion into Afar occurred at the end of the Pliocene. Important marine deposition continued throughout the Lower and Middle Eocene in the eastern Horn, but was abruptly terminated before the Upper Eocene; when deposition recommenced in this region it was very restricted to the present Gulf of Aden and Indian Ocean coastal belts, that is, during the Oligocene and Miocene.

Immediately consequent upon the Upper Eocene uplift of the Arabo-Ethiopian Swell was the extrusion up both fissures and pipes of extremely fluid basaltic lavas. More-silicic lavas, together with pyroclasts and lacustrine sediments, are commonly interbedded in the upper part of these basalts, the whole comprising the Trap Series. These flood lavas attain a maximum thickness of over 3500m in northern Ethiopia. Chemically they are alkaline, and the silicic varieties are often hyperalkaline, for example the Adua-Axum, Senafe, Fantale, and Wachacha suites. The Trap Series is dated as Oligocene, extending up into the Miocene in southern Ethiopia where pyroclasts become more abundant.

Rifting followed upon extrusion of the Trap Series, and indeed the last hyperalkaline lavas of the series were contemporaneous with the initial faulting. Whereas the pre-Cambrian and Mesozoic rocks only outcrop, in association with the Rift System, in the extreme northern and southern regions, the Trap Series forms the floors and walls of the whole main central region. Locally, post-rifting lavas of the Aden Volcanic Series, and Pleistocene pluvial lacustrine sediments, may cover the Trap Series lavas, but never in sufficient thickness nor extent to modify the statement above, that the sub-horizontal Trap Series strata floor the major part of the Ethiopian Rift System and are exposed up and along the rift walls.

IV. The Units of the Ethiopian Rift System

Sufficient detailed work has not yet been done on the Ethiopian Rift System to warrant an historical treatment of the various events which have given rise to it in its present form. All that is now possible is a descriptive account of the degree and extent of faulting along the boundaries of the system; post-rifting tectonics and vulcanicity within the Rift System will be discussed in a later section.

The Ethiopian Rift System may conveniently be sub-divided into the following units:

(a) The Lake Rudolf Rift (extending northwards from the Gregory Rift of Kenya)
(b) The Lake Stefanie Rift
(c) The Main Ethiopian Rift, funneling out northwards into:
(d) Afar
(e) The Red Sea and Gulf of Aden Rifts insofar as these affect the structure of Afar.
(f) Other suspected associated faulting, more especially the large-scale single-line (block) faulting which limits the Ethiopian Plateau to the west in the vicinity of the Ethiopia-Sudan border.

(a) The Lake Rudolf Rift

Lake Rudolf lies within a rather poorly defined rift on the borders of Kenya and Ethiopia. The connection with the Gregory Rift of central Kenya is not well developed, this latter rift widening out northwards into a downwarped plain with only minor boundary faulting north of Lake Baringo. It is significant that, as here, where the Swell uplift was slight so the rifting has been minor.

In Ethiopia the Lake Rudolf Rift continues northwards and determines the lower Omo valley, the meandering course of the Omo river being there confined to the graben. It has been postulated by various Italian authors (see Dainelli 1943, for résumé) that this rift continues northwards from Shoa Ghimira, buried beneath Trap Series lavas, through Kaffa-Jimma, along the Didessa valley, skirting west of Lake Tana, and northwards to form the Baraka valley before supposedly joining the Red Sea Rift at the Eritrea-Sudan coastal border region. This postulation, however, remains pure conjecture, and considering the relationship of the Trap Series lavas to rift faulting elsewhere in Ethiopia the existence of any such pre-Trappean rift is most improbable. Again, faulting on the western side of the Didessa valley is downthrown west, and not to the east as the above hypothesis pre-supposes. However, the occurrence of fairly recent lavas equivalent to the Aden Volcanic Series of the Rift System in the lower Omo valley, within the Abbai basin, over large areas south of Lake Tana, and north of Amba Bircutan, Tigrai, should be noted as coinciding closely with this supposed rift.

Confining discussion to the Lake Rudolf Rift proper, well developed step-faulting of up to several hundred metres displacement occurs along the western slopes of Mts. Nyiru (2805m) and Kulal (2290m). A steep fault ? scarp extending for about 30Km immediately to the north of Mt. Kulal continues for at least another 100Km, tending in complex fashion to diverge more and more north-eastwards towards the Lake Stefanie Rift. On the western side of Lake Rudolf evident faulting is less common except near the southern end of the lake where fresh, curvilinear faults, downthrown east, run N.N. W.wards from the active volcanic region about Teleki and determine the lake shore and the edge of the Loriyu Plateau.

The northerly half of the Lake Rudolf Rift would be more accurately described as a downwarped flexure rather than as a true rift valley. To the north, however, the lower Omo valley has the form of a definite graben, but there is no reliable tectonic data available from this region.

(b) Lake Stefanie Rift

The extent and magnitude of rift faulting in the Lake Stefanie Rift is unknown. It seems that the swamp itself, lying at an elevation of about 520m, occupies a deep rift whose width is about 40Km, the direction of faulting being N.N.E.-S.S.W.. To the north the faulting extends, probably continuously, to form the Galana-Dullei graben; to the south it extends in poorly-defined manner southeastwards to the region of Mt. Kulal in the Lake Rudolf basin.

Though occurring nearly 200Km east of Lake Stefanie, the faulting of the Mega region may be conveniently mentioned here. This faulting has caused upthrow of the hills amongst which Mega is situated, the tectonic trend being N.N.W.-S.S.E.; a maximum downthrow of 400m to the east in a

single, un-stepped scarp is developed immediately east of the British Consulate, where the rocks exposed are migmatised arkoses. This line of movement, closely associated with recent vulcanicity and fresh explosion craters, continues farther N.N.W. to form the steep eastern scarp of Gara Fulli, but whether it extends beyond Yavello is unknown. This faulting, and also the possible fault-scarp, now very much denuded, running from Moyale W.N.W.wards to the west of Mega, are undoubtedly an ultimate southerly expression of the definite true rifting of the Main Ethiopian Rift south of Burji.

(c) The Main Ethiopian Rift

The African Rift System is most typically developed in Ethiopia in the section termed the Main Ethiopian Rift, which extends from Lake Chamo in the south to Afar in the north. The northern boundary is artificial in that the Main Ethiopian Rift gradually funnels outwards into Afar at about the latitude of Addis Ababa, but for the sake of convenience it may be taken as an east-west line drawn through Awash Station and Addis Ababa.

In an earlier paper (Mohr 1960) the author has published two preliminary maps showing all important faults, explosion craters, subsidence craters, volcanic craters and recent lava flows in the northern and southern sections of the Main Ethiopian Rift, that is, north and south of the Maki-Awash watershed, respectively. No specific discussion accompanied the publication of these maps, however.

The Main Ethiopian Rift has been mapped by the author as far south as Alghe, but as mentioned above there is evidence that lesser faulting continues south as far as Mega. In the lake Chamo basin little major faulting is manifested, except to the north of the lake. To the east, however, rises the remarkable pre-Cambrian block of the Amaro Mts, a horst marking a forking of the Rift southwards from this region; the more intensely faulted branch passes between the Amaro Mts and the edge of the Somalian Plateau to the east as formed by Mt. Jabasire. Lake Chamo occupies the less intensely faulted branch of the Rift to the west of the Amaro Mts. Whether the Amaro Mts. merely represent a plateau remnant left upstanding above the graben to either side, or whether the block has been squeezed up from the Rift floor, possibly by processes similar to those which formed the Ruwenzori horst, is uncertain, However, the presence of a 150-200m 'terrace' along the eastern side of the Amaro Mts. seems to represent up-faulting of the peripheral region of the Rift floor, and by its freshness at the basal terminations of several large erosion gullies indicates that fairly recent uplift has played at least a part in the formation of this block. About 60Km long, the Amaro Mts. ridge falls away both to north and south along its longitudinal axis.

Lake Margherita occupies the shallow bottom of a large internal drainage basin. West of the lake rise the Gughe Mts., the remnants of a huge Trap Series basalt volcano. Faulting is little in evidence on this side of the lake except close to the shore-line which is determined by N.N.E.-S.S.W. faults. Lines of islands in the southern part of the lake run parallel to this faulting direction. It is notable that the throw of the faults west of Lake Margherita is down to the west, warping and tilting down to the east having contained the lake in its basin. East of Lake Margherita major faulting has occurred along two N.N.E.-S.S.W. zones, one west and one east of Dilla. The easterly zone faulting forms the main scarp of the Somalian Plateau overlooking the Rift, with complex step and scissor faulting being especially well developed farther south in the Trap Series silicic pyroclasts of Mt. Jabasire. The westerly zone faulting is smaller in magnitude but is younger and better preserved; near Dilla it exposes highly manganiferous trachytes of the Trap Series.

The main eastern scarp of the Rift continues from Dilla linearly to the immediate east of Wondo where it forms a single, huge and somewhat denuded wall with a total vertical displacement of at least 1000m. North of Wondo the throw of this boundary fault decreases but the fault itself remains sharp and clearly defined until the Lake Awasa basin. The lake Awasa basin is unique in the Main Ethiopian Rift in that it is a basin totally enclosed by faulting, tranverse rift faults bounding it to the north and south. The northern boundary fault, downthrown south by up to 100m, displaces Pleistocene pluvial lacustrine sediments and is associated with the dormant volcano of Chubbi. The western boundary scarp of the Lake Awasa basin is remarkable in that adjoining erosion spurs now have their apices above the plateau elevation to the west indicating some recent reverse movements along this fault zone. The unusually high elevation of the Lake Awasa basin with regard to its position along the Rift valley profile must be explained by upwarping of a gentle but extensive nature along the Rift floor.

East of Shashamanne and Neghelle the eastern scarp of the Rift becomes much less clearly defined, and the Plateau-Rift boundary is formed merely of a very dissected surface of Trap Series lavas. To the north, in the Galla Lakes basin, however, the eastern scarp again resumes a definite form. The western scarp of the Rift, all the way from the Lake Margherita basin north to the Galla Lakes basin, is much less in evidence than the eastern scarp. Whether this is because original old faults have now been denuded beyond easy recognition, or whether there has never been any faulting along this boundary, is unknown, but the phenomenon of a larger and fresher eastern scarp compared with the western is typical of the Main Ethiopian Rift as a whole. A similar observation has been made in the Gregory Rift of Kenya.

The eastern scarp of the Rift, with a total displacement of about 800m east of Lake Langano,continues north towards Aselle, though the Quaternary Wonji Fault Belt of the Rift floor curves very close to it in the Lake Zwai region. That this scarp tends to be less dissected in the Galla Lakes basin than farther south in Sidamo is considered to be due solely to climatic factors, and not to any significant difference in age. A lateral displacement of the eastern scarp occurs in the latitude of Mts. Chilalo and Badda, being about 20Km eastwards to the north; the precise nature of this displacement has not been studied. Mt. Chilalo is a fairly well preserved late-Trap Series silicic volcano situated at the precise western end of this lateral displacement. At the eastern end, Mt. Badda, the rift-faulting to the north is directionally continuous with the peculiar ridge joining Mts. Badda and Kakka. This linear ridge is formed of a sub-parallel swarm of dykes, first observed by the author and as yet not investigated. Farther north near Sire magnificent step and scissor faulting causes a total displacement of nearly 900m.

The western scarp of the Rift in this region becomes increasingly more definite from Mt. Amba northwards to the Guraghe Mts. The latter owe their origin solely to a strong upwarping of the Plateau Trap Series strata towards the Rift. This is the best example of such upwarping known to the author in Ethiopia, and it occurs where the western boundary faulting is unusually strongly developed.

The Rift floor attains its maximum general elevation in Ethiopia at the watershed of the Maki and Awash rivers at a little over 1800m. (elevation not yet precisely determined).

The faulting of the northern section of the Main Ethiopian Rift is very complex. The eastern margin of the Rift as far north-east as Ghelemso is composed of giant stepped scarps, and such features extend east as far as Dire Dawa. These stepped scarps, however, are considerably denuded and it is probable that they merely represent recession from the original tectonic line under erosive forces, and are now solely emphasising the horizontal structure of the Trap Series lavas. This horizontal structure of the Trap Series, and also of the underlying Mesozoic sediments, has given rise to much confusion in the past with regard to identification of supposed erosion surfaces (Thus see Dainelli's (1943) criticism of Merla and Minucci (1938), but also the author's criticism of Dainelli in his forthcoming work on the geology of Ethiopia). A similar erosional recession has occurred along the western boundary of Afar, thereby suggesting that Afar is considerably older than the Main Ethiopian Rift.

The western boundary of the northern section of the Main Ethiopian Rift is even less clearly defined than to the south. From Addis Ababa to Mojjo there is, except for a few quite minor faults of Quaternary age, a gentle gradient all the way from the Plateau down to the Rift floor. It has been supposed that the absence of a true Rift scarp east of Addis Ababa is due to a crossing of E.N.E.-W.S.W. Gulf of Aden faulting from the northern margin of the Somalian Plateau across the Main Ethiopian Rift to the Ethiopian Plateau; however, there is no substantial evidence for this hypothesis, and the large fault running from north-west of Addis Ababa westwards to Ambo is downthrown 250-300m to the south, the contrary direction. It is shown on map 2 that faulting in the Addis Ababa region is otherwise very minor, and trends sub-parallel to the recent faulting of the Rift floor. It is perhaps significant that the presence of the late-Trap series volcanoes Yerer, Furi, Bokam and Wachacha is associated with the absence of the Rift scarp; the peculiar petrography of the lavas of these trachytic centres remarks their E.S.E.-W.N.W. alignment, the same direction as the Chilalo-Badda displacement. Whilst it is possible that lavas and tuffs from these volcanoes buried and destroyed original fault scarps in the Addis Ababa region, yet it is more probable that some peculiar deep-seated phenomena accounted for both the presence of the volcanoes and the absence of boundary faulting. This is further suggested by the occurrence of large clockwise wrench-faulting associated with the Bishoftu explosion craters, east of Addis Ababa (Mohr 1961A). These wrench faults are now mostly buried beneath later lavas and lacustrine sediments, all of which, however, the explosion craters post-date.

Some general features of the Main Ethiopian Rift worthy of summary note are: The eastern scarp is better developed than the western scarp; the average total throw of the eastern boundary faults is between 500 and 1000m, with common step and scissor faulting. The average distance separating the eastern and western boundary faults, where the latter is developed, is about 80Km; this is rather more than the average width of the East African Rift System to the south, and may presage the approach to Afar to the north. The only known major tranverse faults in the Main Ethiopian Rift form the Lake Awasa basin; other variations in Rift floor elevation, away from volcanoes, must therefore be ascribed to gentle folding such as is observed in the syncline north of the Awash river and west of the Adama-Aselle road. All the boundary faults observed in the Main Ethiopian Rift are normal faults; although these are of considerable magnitude along the eastern boundary, their displacements are never such as to expose the Mesozoic strata beneath the Trap Series, though the common development of step-faulting obviously inhibits the chance of such exposure.

(d) Afar

The western boundary of Afar is formed by an immense, but extremely and broadly denuded scarp extending from Mt. Meghezez, east of Addis Ababa, north through Wallo, Tigrai, to Eritrea where it joins with the Red Sea Rift. Most, if not all, of the length of this west boundary scarp is an erosional feature due to westward migration of the original fault-scarp(s) at the expense of the Ethiopian Plateau. The zone of major faulting is thus now situated along an alignment east of the main boundary scarp, usually by a distance of 40-50Km, but sometimes less as in southern Tigrai. The line of original faulting is not always easy to detect, frequently being buried under piedmont, fluvial and lacustrine sediments, and, because of this denudation and deposition, giving no morphological indication of its presence.

Some doubtful faults cut the extraordinarily dissected pile of Mt. Meghezez. In this respect Mt. Meghezez strongly contrasts with the freshly faulted and lacustrine sediment-covered plain to the immediate south of the Kassam River. At Debra Sina the huge erosional scarp, cut back to the Trap Series volcanoes of Mts. Woti and Membret, may be associated with the faulting immediately to the north, especially where, as at Mussolini Pass, the scarp is sheer. From Debra Sina to Karakore faulting orientated N.N.E.-S.S.W. along the present margin of the Ethiopian Plateau is remarkable for downthrows predominantly to the west. This direction of downthrow has been noted at many localities further north and indicates a peculiar downwarping of the Afar depression following upon the straight-forward downfaulting. These faults continue north-east of Karakore, but a branch turns due north and bounds the eastern edge of the Borkenna valley to Combolcha. The western scarp of the Borkenna valley is of less certain tectonic origin, but has a steep, walled form near Majite, thus suggesting that the Borkenna valley is a small graben, 6-10Km wide, lying at the margin of Afar. From May to September 1961 a period of intense earthquake activity was associated with movements along west-downthrown faults in the Karakore region, the most severe shocks having a magnitude of 6.5 (Gouin, P. - data to be published.).

North of Combolcha the west-downthrown faults continue, forming the lake basins of Ardibbo and Haik. Little is known of the erosion scarp overlooking Afar in northern Wallo, but in southern Tigrai the convex curve (facing Afar) of the scarp alignment through northern Shoa and Wallo changes to concave between Waldia and Mai Chew, and thence becomes convex again northwards into Eritrea. This curvilinear form of the scarp reflects the original behaviour of the boundary faults of western Afar, contrary to what the maps of Krenkel (1957) and Voute (1959) etc. hypothetically express.

At Waldia the faulting is aligned N.-S., and, further north, N.N.W.-S.S.E., being downthrown east; here this original fault belt, still cutting Trap Series lavas, is less than 15Km from the present erosional scarp. From about 40Km south of Quoram, and passing just east of this town, the Guf Guf valley extends for a total length of 90Km in a N.-S. direction. The form of the Guf Guf valley is very similar to that of the Borkenna to the south, and indeed both are on a common alignment. The streams in both valleys, which are floored by old lake bed sediments, escape eastwards through gaps at the south-eastern ends of the valleys. Whilst the Borkenna valley probably represents a small graben, however, that of the Guf Guf is formed of a basin in tilted Mesozoic strata (exposed for the first time coming northwards) and Trap Series lavas dipping east, and which have been faulted with western downthrows. Lake Ashangi, north of Quoram, occupies this same type of basin and not a graben.

Between 10 and 30Km south of Quoram a belt of faults running N.E.-S.W. and E.N.E.-W.S.W. cuts the Plateau. Cross-faults at the margin of the Ethiopian Plateau are also known at Amba Alaji (E.-W.) and north of Makalle (E.S.E.-W.N.W.). The throw of these cross-faults is never large (less than 400m to the south) and they peter out westwards into small flexures. They were probably formed by stresses acting on the edge of the Plateau at the time of the main N.-S. Rift System faulting.

The scarp of the Ethiopian Plateau in the region of Quoram reaches a magnitude of 2000m, but the west-facing eastern scarp of the Guf Guf valley has a total displacement of almost 1000m, denudation having removed any morphological evidence of step-faulting. The Mai Chew region is noted for its present-day seismicity, fairly strong shocks being experienced as recently as Oct.-Nov. 1957 (Gouin 1960). North of the Guf Guf valley the belt of the original boundary faults passes about 40Km east of Makalle and curves in convex fashion (facing Afar) passing about 50Km east of Adigrat. The erosional scarp, exposing Trap Series, Mesozoic sandstones, and pre-Cambrian phyllites and schists, manifests a total displacement of nearly 3000m in northern Tigrai. Outliers from the scarp, but west of the original boundary faults, form Mt. Sobni (2551m) east of Adigrat, Mt. Asimba (3248m) near the Eritrean border, and Mt. Swera (3013m) east of Senafe.

North of Senafe where the scarp bends round to a N.W.-S.E. Red Sea trend the Eritrea Sandstone and Trap Series strata are observed to be downwarped from the Plateau to beneath the plains of Afar, similar to the large-scale stratal downwarping of northern Shoa and southern Tigrai. This phenomenon indicates that west of the western boundary faults of Afar, downwarping has contributed on an important scale to the formation of the Afar depression, morphological evidence suggesting that the downwarping occurred much later than the boundary faulting. It might be proposed that rifting here preceded eruption of the Trap Series whose lavas thence flowed down into Afar, but the location of the original fault belt farther east, as well as the warping of the underlying Eritrean Sandstone, is unfavourable to such an hypothesis.

East of Asmara the deeply denuded scarp falls from a Plateau elevation of about 2500m, and farther north extends along a line parallel to the Red Sea coast through Mt. Ira (2618m) down to the Baraka valley. In Samhar, where the very steep erosional scarp is 1500-2000m high, the original faulting, presuming it to lie to the east of this scarp, is now buried under late Miocene marine sediments. Between Massawa and Asmara relatively recent faulting has given rise to platforms which have been misinterpreted (Dixey 1946 pp354-5) as representing denudation levels. Note: For a more sober interpretation of the geomorphology of this region see Abul-Haggag (1961); for a correct factual report of the geology see Merla and Minucci (1938) and Dainelli (1943).

Similar step-faulting probably accounts for the fact that the upper parts of the Comayli, Haddas Shaghede, and Alighede stream valleys, rather than descending the scarp directly eastwards, do so at a shallow angle to the scarp edge, in a northerly direction.

One of the most striking, and puzzling, features of the Red Sea Rift is the manner in which its western boundary fault-zone branches in the vicinity of the Gulf of Zula. The westerly branch curves southwards to form the edge of the Ethiopian Plateau as considered above; this is the branch which would appear to follow the more conformable and orthodox trend. The other branch continues south-eastwards from the Gulf of Zula to form the relatively uplifted horst of the Danakil Alps. The extremely denuded scarp of this horst faces south-westwards across Afar, the north-east side declining gently beneath the Red Sea. Between these two branches lies the northern apex of Afar which though a sunken region, is much less so than the Red Sea proper.

Dainelli (1943) considers the Salt Plain to represent a graben tectonically continuous with the faulting of the Gulf of Zula; no such faulting is evidenced along the margins of the Salt Plain though extensive flood basalts from the Erta-ale, Afrera and Afdera volcanic groups, as well as the late Pliocene-early Pleistocene marine sediments, would have covered any earlier faults and filled in the graben. The great thickness of salt beneath the Salt Plain, 600m +, supports the concept of a graben, about 60Km in width, as does faulting along the same alignment forming the basins of Lakes Assal and Halol, and the Gubet Kharab, in French Somaliland.

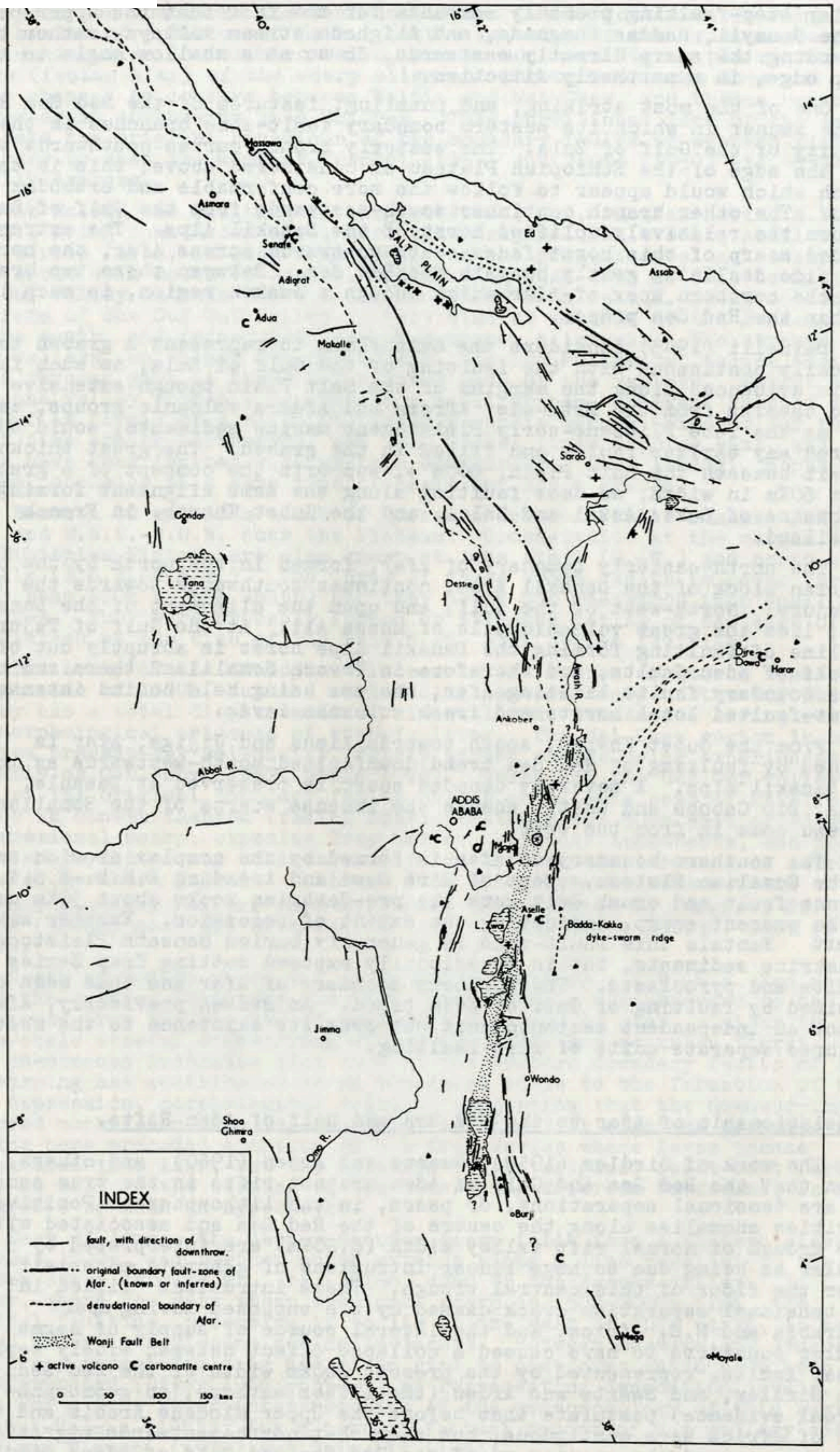
The north-easterly boundary of Afar, formed in the north by the pre-Cambrian block of the Danakil Alps, continues southwards towards the Gulf of Tajura. North-west of the Gulf, and upon the alignment of the Danakil Alps, lies the great volcanic pile of Mussa Ali. At the Gulf of Tajura the line of faulting forming the Danakil Alps horst is abruptly cut off by Gulf of Aden faults, and therefore in French Somaliland there are no major boundary faults limiting Afar, the sea being held behind intensely recent-faulted local horsts and fresh volcanic lavas.

From the Gubet Kharab, south towards Aisha and Jijiga, Afar is bounded by faulting of Red Sea trend downfaulted south-westwards as in the Danakil Alps. A severely denuded scarp is preserved at Dawanle, Aisha, Bio Caboba and Gokti, whence the immense scarps of the Somalian Plateau come in from the west.

The southern boundary of Afar is formed by the complex erosion scarps of the Somalian Plateau. West of Dire Dawa and trending E.N.E.-W.S.W. an intense fault and crush belt cuts the pre-Cambrian rocks about 30Km north of the present scarp, indicating the extent of recession. Farther west toward Fantale this fault-zone is generally buried beneath Pleistocene lacustrine sediments, but is occasionally exposed cutting Trap Series basalts and pyroclasts. The southern boundary of Afar has thus been determined by faulting of Gulf of Aden trend. As stated previously, Afar is not an independent tectonic unit but owes its existence to the meeting of three separate units of rift faulting.

V. Relationship of Afar to the Red Sea and Gulf of Aden Rifts.

The work of Girdler (1958), Swartz and Arden (1960), and others, has shown that the Red Sea and Gulf of Aden are not rifts in the true sense but are tensional separations, or paars, in the lithosphere. Positive gravities anomalies along the centre of the Red Sea and associated with a deep trough of normal rift valley width (c.60Km) are interpreted by Girdler as being due to huge linear intrusions of gabbroic material under the floor of this central trough. These intrusions 'filled in' the tensional separation crack caused by the supposed moving apart of Arabia and N.E. Africa, and the lateral source of supply of magma Girdler considers to have caused a collapse effect between widely separated linear faults, represented by the present 200Km width of the Red Sea. Both Girdler, and Swartz and Arden (the latter authors, on geomorphological evidence) postulate that before the Upper Miocene Arabia and the Horn of Africa were contiguous, but then that north-eastwards migration of Arabia caused the opening up of the Red Sea and Gulf of Aden; Girdler



Map 2. Known major faulting in the Ethiopian Rift System.

postulates that the amount of separation is represented by the central trough; Swartz and Arden, that the remarkable coincidence of form of the western and eastern shores of the Red Sea indicates that the amount of separation is represented by the whole width of the Red Sea 'Rift'.

This paper is not the place for a fully critical review of the various theories of origin of the Red Sea and Gulf of Aden. The author will merely restrict discussion insofar as his geological observations of Afar are affected by the increasingly accepted tensional-separation origin of the Red Sea.

If the present coastline of Arabia was once contiguous with that of the Horn it is evident that the whole of Afar must be included in the Red Sea paar as being once spatially occupied by S.W. Arabia. But the known geology and structure of Afar is such as to make this hypothesis untenable. Apart from the immense block of the Danakil Alps, a pre-Cambrian mass of gneisses and schists overlain by marine Mesozoic sediments and Tertiary Trap Series lavas which all dip gently north-eastwards, central Afar is entirely floored by pre-rifting Trap Series lavas, where not covered by more recent lavas and sediments. In Tigrai and Eritrea pre-Cambrian schists and Mesozoic sandstones and limestones are exposed underlying the Trap Series on the floor of Afar, and also in French Somaliland. The inference, therefore, and one supported by the gentle easterly dips of the strata along the western margin of Afar in Shoa, Wallo and Tigrai, is that Afar is underlain by the same rocks as form the Ethiopian and Somalian Plateaux, that is to say, Afar was once a part of the Arabo-Ethiopian Swell surface. The only possible exception to this statement is the Salt Plain, which may prove to be a tensional crack rather than a filled-in graben.

It is therefore considered that the structure of Afar is such as to preclude the hypothesis of a once contiguous Arabia and Horn as represented by their present-day coastlines. What tensional separation has taken place has only been of sufficient magnitude to form the central Red Sea trough, and beneath the shallow margins of the Red Sea a normal succession of pre-Cambrian, Mesozoic sediments and Tertiary lavas, similar to that of Afar, can be expected. In a personal communication Girdler (1961) has geophysical data to suggest that the gabbroic intrusions of the central Red Sea trough enter the Eritrean coast-line in the vicinity of Ed from the north. This suggests that tensional separation may have occurred beneath Afar without breaking up the overlying Danakil Alps block, but until further information is available it would be foolhardy to state more than that Afar represents a down-faulted and downwarped triangular area of the original Arabo-Ethiopian Swell at the intersection of three units of rifting.

VI. Other Faulting related to the Rift System in Ethiopia

Dainelli (1943) first suggested, from a consideration of the pre-Cambrian-surface isohypsals, that the western scarp of the Ethiopian Plateau overlooking Sudan is of original tectonic origin. This has been confirmed by the author's field observations at Dul, Beni Shangul, where epi-schists are downthrown 700m to the west. Much fresher faulting trending from the Lake Tana basin on the Plateau crosses the Atbara valley in the vicinity of Galabat; the predominant orientation of this faulting is N.W.-S.E., downthrown S.W.. These fresh faults seem to represent renewed movements along older lines, for whilst most of the faults cut the Trap Series here in western Beghemeder others are partially buried beneath these lavas. This accords with Jepson's (1960) report of an unconformity within the Trap Series of western Gojjam to the south, tilting movements having occurred along faults farther west during Trappean times.

North of Kassala the existence of major N.-S. faulting, downthrown west, along the Gash valley has been proved by gravity survey, but in the Langeb valley faults orientated N.30°E and cutting Tertiary basalts are downthrown a total of 200m to the east (Delaney 1954). The nature of the western scarp of the Ethiopian Plateau in Ilubabor, Kaffa-Jimma and Gamu-Gofa has not yet been examined, but again the sudden change in the elevation of the pre-Cambrian surface suggests major N.-S. and N.N.W.-S.S.E. faulting, downthrown west.

Many large faults are known cutting the Trap Series on the Ethiopian

Plateau. In this respect the Ethiopian Plateau contrasts markedly with the Somalian Plateau where tectonic influences have been slight. Near the Dabana-Didessa confluence the courses of both rivers are largely determined by N.10°W faulting downthrown west; this faulting continues in curvilinear fashion to south of Kumbari. About 30Km west of the western shores of Lake Tana cross-faulting, jointing and dyke-intrusions are directed N.W.-S.E. and N.E.-S.W., and are especially well developed west and south-west of Ismala Georgis. This is the faulting which continues northwards to Galabat.

The Lake Tana basin, dammed at its southern end by recent basalts, shows little evidence of faulting. Small faults running approximately N.20°E occur at the south-east and south-west margins of the lake and also to the north of Gorgora, but not on a scale sufficient to alter the fact that Lake Tana occupies a tilted and downwarped rather than a faulted basin. This is confirmed by the shallowness of the basin, the maximum depth of the lake being only 14m. However, the south-easterly dip of the Trap Series lavas on the western side of Lake Tana indicates that faulting movements which occurred along the border faults farther west were associated with uplift and tilting, and causing modification of river drainage from westerly to northerly and southerly (eg. the Abbai), and, with extrusion of basalts in the Bahar Dar region, the formation of the Lake Tana basin. Similar minor faulting to that of the Lake Tana basin occurs farther south at Danghila and west of Burie, again associated with extensive recent basalts and numerous explosion craters.

Other notable large faults on the Ethiopian Plateau cutting the Trap Series include the E.-W. Tulu Walel fault, downthrown north, in Wollega, and the complex of large, sub-parallel N.-S. faults, downthrown east, in northern Jimma. As a generalised summary it can be stated that faulting on the Ethiopian Plateau north of about 10°N trends mainly N.N.E.-S.S.W., including the crush faulting of the Simien Mts., and downthrown W., whereas south of about 10°N the faulting usually runs close to an E.-W. direction.

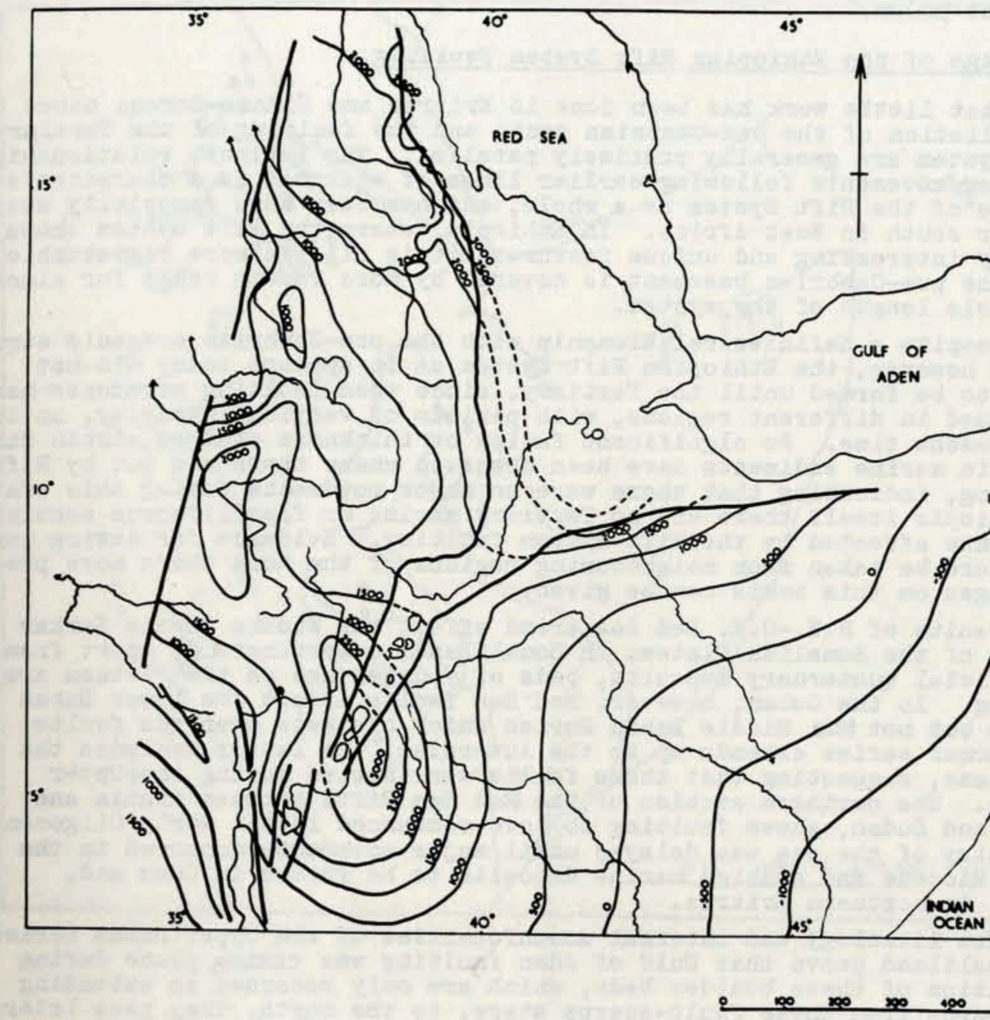
VII. Relationship of the Ethiopian Rift System to the Arabo-Ethiopian Swell

The uplift of the Arabo-Ethiopian Swell during the Upper Eocene (Dainelli 1943, Beydoun 1960), a movement not to be confused with the termination of subsidence which brought an end to marine sedimentation over the region in a regressive pattern from the Kimmeridgian to the Middle Eocene, is a phenomenon to which the ensuing formation of the Rift System was intimately related. Whatever the cause the Swell, this longitudinal uparching was such that a weakness developed associated with its crest which resulted in faulting and subsidence. Prior to this rifting, however, fissuring occurred with extrusions of basalt lavas covering most of the Swell. Thickness measurements of the Trap Series indicate that the fissures and centres were dominantly situated a little to the west of the swell crest. The reason for this is not known.

The precise measurement of the amount of Upper Eocene uplift over Ethiopia is a difficult problem whose solution has so far found its best expression in the map of Dainelli (1943) which shows the 'Crystalline Basement' isohypsals for the Horn of Africa. These lines fail to take into account the elevation of the pre-Cambrian surface prior to the uplift, though as this surface had the form of a peneplain close to sea-level the difference between the degree of uplift and the present isohypsals should not be serious. Over the Rift System, of course, values must be extrapolated.

Map 3 shows these pre-Cambrian-surface isohypsals for Ethiopia (modified by the author after Dainelli); unfortunately no similar data are yet available for S.W. Arabia. Two maxima of uplift may be noted, both reaching above 3000m and both with long axes trending N.N.W. -S.S.E., one covering the Lake Margherita region, the other north-central Tigrai and Eritrea. Separating these two axes of maxima, which are offset by 500Km, is a trough, or minimum, running S.S.E. from the Lake Tana region through Addis Ababa and along the Webi Shebeli basin.

The Ethiopian Rift System has formed along the swell crests, and runs parallel to the isohypsals, in the Red Sea and Gulf of Aden sections. However, the Main Ethiopian Rift, trending N.N.E.-S.S.W., diverges appreciably from the long axis of the Lake Margherita maximum. The Lake Rudolf and Lake Stefanie Rifts show a much closer relation to the direc-



Map 3. Basement Complex surface isohypsals.

tion of the isohypsals than does the Main Ethiopian Rift, and therefore, despite the irregularity of the latter, there is an unmistakable association of the Rift System faulting with the swell crests. The total vertical flexure of the pre-Cambrian basement of the Horn of Africa was at least 5000m.

VIII. Age of the Ethiopian Rift System Faulting.

What little work has been done in Eritrea and Sidamo-Borana shows that the foliation of the pre-Cambrian rocks and the faulting of the Tertiary Rift System are generally precisely parallel. The intimate relationship of later movements following earlier lines of weakness is a characteristic feature of the Rift System as a whole, and has been more especially studied farther south in East Africa. In Ethiopia, where the Rift System shows so many interesting and unique features, it is all the more regrettable that the pre-Cambrian basement is covered by more recent rocks for almost the whole length of the system.

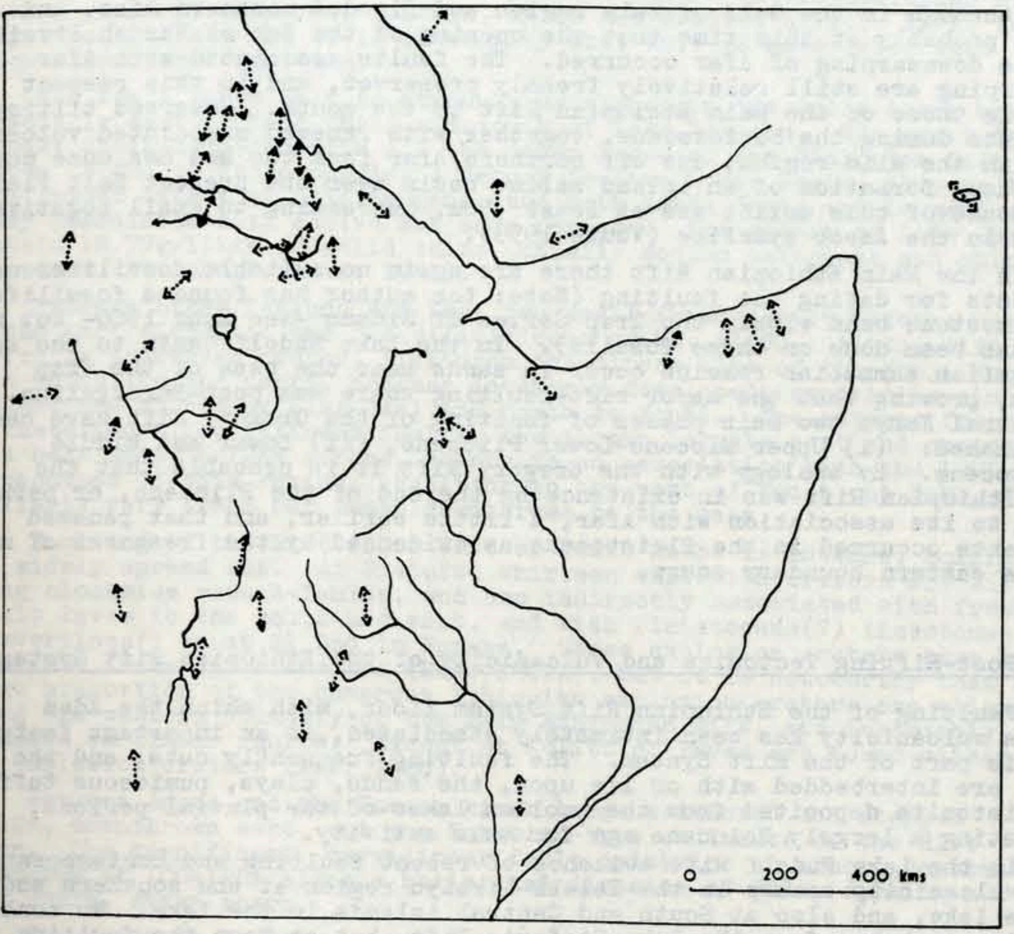
Despite a definite relationship with the pre-Cambrian orogenic structures, however, the Ethiopian Rift System as it appears today did not begin to be formed until the Tertiary, since when faulting movements have continued in different regions, with periods of varying intensity, up to the present time. No significant facies or thickness changes within the Mesozoic marine sediments have been observed where these are cut by Rift faulting, indicating that there were no major movements during this era*. In Ethiopia itself there are no Tertiary marine or fossiliferous continental sediments affected by the Rift System faulting. Evidence for dating must therefore be taken from neighbouring regions of the Horn where more precise ages on this basis can be given.

Faults of N.W.-S.E. Red Sea trend affect the Middle Eocene Karkar Series of the Somalian Plateau in Somaliland; unfortunately, apart from superficial Quaternary deposits, beds of younger age on the Plateau are lacking. In the Guban, however, Red Sea faults affect the Lower Daban Series but not the Middle Daban Series which blankets over the faults; the former series extends up to the Auversian, the latter includes the Oligocene, suggesting that these faults were active during the Upper Eocene. The northern section of the Red Sea Rift, between Arabia and Egypt and Sudan, shows faulting to have commenced in the early Oligocene, but entry of the sea was delayed until major movements occurred in the Lower Miocene and enabled marine deposits to be formed in Suez and, later, in northern Eritrea.

The lithology and internal unconformities of the Upper Daban Series in Somaliland prove that Gulf of Aden faulting was taking place during deposition of these boulder beds, which are only recorded as extending northwards from these fault-scarps where, to the north, they pass laterally into the Lower Miocene Dubar Limestone. Major Gulf of Aden movements therefore occurred from the Aquitanian to the Burdigalian, but restriction of the Oligocene Middle Daban Series to the present Gulf of Aden region indicates that some faulting was already occurring during that time. South of Berbera, and in French Somaliland, faults of Gulf of Aden trend cut Aden Volcanic Series lavas, proving activity extending up into the Quaternary, and indeed it is considered that the Straits of Bab el Mandeb were only opened as late as the Middle Pliocene.

By analogy with the Red Sea and Gulf of Aden Rifts the faulting of Afar is presumed to have begun in the late Oligocene, with the major movements taking place in the Miocene. This age is consistent with the

*Note: In Shoa, Wallo and Arussi there is a definite thickening, accompanied by a downwarping, of the Mesozoic strata where these approach and presumably plunge beneath the Main Ethiopian Rift. This parallels the downwarping of the margins of Afar, where however the movements included, and so post-dated the formation of, the Trap Series strata. It is therefore possible that a broad, rather shallow trough was in existence along the northern part of the Main Ethiopian Rift in Mesozoic times (but not in the southern part of the Main Ethiopian Rift where marine Mesozoic sediments were never deposited). This trough, however, barely affected the regular north-westerly transgression of the Mesozoic sea and its later regression, and a much more pronounced trough existed over eastern Arussi during the Cretaceous, a region not related tectonically in any known way with the Rift system.



Map 4. Prevalent directions of Basement foliation.

very denuded nature of the boundary scarps of Afar, which have received negligible renewal. The absence of Miocene marine sediments from Afar shows that due to unknown factors the region was not depressed below sea-level with the Red Sea. However, towards the end of the Pliocene the sea broke through in the Gulf of Zula region and flooded northern Afar, and it was probably at this time that the opening of the Bab el Mandeb Straits and the downwarping of Afar occurred. The faults associated with Afar downwarping are still relatively freshly preserved, and in this respect resemble those of the Main Ethiopian Rift to the south. Reversed tilting movements during the Pleistocene, together with renewed associated vulcanicity in the Alid region, cut off northern Afar from the Red Sea once more and caused formation of an inland saline basin over the present Salt Plain. The amount of this uplift was at least 350m, decreasing to small negative values in the Assab syncline (Voute 1959).

In the Main Ethiopian Rift there are again no suitable fossiliferous sediments for dating the faulting (Note: the author has found a fossiliferous limestone band within the Trap Series of Sidamo -see Mohr 1960- but no work has been done on these fossils). In the Lake Rudolf basin to the south Burdigalian mammalian remains occur in sands near the base of the Trap Series, proving that the major rift-faulting there was post-Burdigalian. In central Kenya two main phases of faulting of the Gregory Rift have been established: (i) Upper Miocene-Lower Pliocene, (ii) Lower and Middle Pleistocene. By analogy with the Gregory Rift it is probable that the Main Ethiopian Rift was in existence by the end of the Pliocene, or perhaps, owing to its association with Afar, a little earlier, and that renewed movements occurred in the Pleistocene as evidenced by the freshness of much of the eastern boundary scarp.

IX. Post-Rifting Tectonics and Vulcanicity of the Ethiopian Rift System Floor

Faulting of the Ethiopian Rift System floor, with which the Aden Series vulcanicity has been intimately associated, is an important feature of this part of the Rift System. The faulting frequently cuts, and the lavas are interbedded with or lie upon, the sands, clays, pumiceous tuffs and diatomite deposited from the swollen lakes of the pluvial periods, indicating a largely Holocene age for this activity.

In the Lake Rudolf Rift evidence of recent faulting and contemporaneous vulcanicity occurs in the Teleki-Likaiyu region at the southern end of the lake, and also at South and Central islands in the lake. No such activity is known from the Lake Stefanie Rift, but at Mega the faulting previously described cuts Pleistocene (?) limestones which themselves post-date the freshly-preserved explosion craters at El Sod (Mohr 1960). Scoriaceous olivine basalt lavas and cinders have been extruded and ejected from cones situated along the Mega fault lines.

Farther north, within the Main Ethiopian Rift, evidence of recent vulcanicity is not encountered until north of Lake Margherita where a small basalt lava cone is associated with a remarkably intense belt of faulting trending N.N.E. toward Lake Awasa, and with small downthrows to the west. This belt of faulting, termed the Wonji Fault Belt, is manifested farther south in the narrow strip of land separating Lakes Chamo and Margherita, and by the alignment of numerous small islands in Lake Margherita. West of Gado the silicic centre of Mt. Kiraka is situated on the Wonji Fault Belt, but its rather denuded form indicates an older age than for the recent basalt centres.

To the north the Wonji Fault Belt passes immediately west of the Lake Awasa basin, though it is not as intensely developed there as in the Lake Margherita region. Many of these small faults in the Lake Awasa region show an easterly downthrown, as do the larger ones which form the western boundary of the Lake Awasa basin. As mentioned previously, reversed movements have been detected along these boundary faults, and indeed the faults of the whole of the Wonji Fault Belt show a propensity for variable direction of downthrown. Directly north of Lake Awasa and situated upon the northern boundary transverse fault lies the dormant volcanic centre of Chubbi. Chubbi forms a flat, dome-shaped hill composed of very fresh rhyolite obsidian flows. Greenfield (1960) has mapped at least three phases of flow activity, the flows averaging 15-20m thickness which is large for

a glassy lava. Greenfield has detected at least two buried centres of eruption, the higher and larger of which shows some circular subsidence. Intense fumarolic activity is at present being manifested upon an older pyroclastic cone. Chubbi is the only known centre in the Ethiopian Rift System, apart perhaps from Fantale, which has erupted silicic lavas in very recent times, and it is noteworthy that this is associated with unique transverse faulting.

The Wonji Fault Belt is strongly developed in the Galla Lakes basin, especially east of Lake Shala and south of Lake Langano. The great depth of Lake Shala compared with all the other lakes of the Ethiopian Rift System is due to its occupying a deeply faulted local basin; this is true to a lesser extent of Lake Langano, and both Lakes Shala and Langano are today associated with active hot soda springs. The waters of Lake Shala contain 16.77g/litre of solid salts, chiefly sodium carbonate and chloride. (Missione Ittiologica etc. 1941).

Between Lakes Langano and Zwai two small fresh basalt patches occur on the east slopes of the old silicic cone of Mt. Alutu. Alutu, with a perfectly preserved crater, lies upon the direct line of the Wonji Fault Belt which, to the north, becomes intensely developed, especially along the eastern shores of Lake Zwai and north to Wonji. The extreme freshness of these short, curvilinear faults, downthrown largely east and concentrated in a belt about 5-12Km across, points to an association with the 1906-07 earthquakes of this region. Faulting to the west of Wonji, at Koka, is similarly very fresh but shows downthrows to the west.

Faulting of the Rift floor east of Addis Ababa is intense, complex, and widely spread out. At Bishoftu thirteen explosion craters are situated along clockwise wrench-faults, and are indirectly associated with fresh basalt lavas to the south and east, and with Pleistocene(?) limestones (travertines?) as at El Sod in Borana. These explosion craters have been described in detail elsewhere (Mohr 1961A), but it is noteworthy that a large proportion of the numerous Ethiopian explosion craters are aligned along the western boundary of the Main Ethiopian Rift, and invariably situated on linear faults. Except at Kolito no lavas are found within the explosion craters (Mohr 1960).

Between Adama and the Kassam river large scissored and stepped faults, downthrown east, cut the Kamasian-type sediments of the Rift floor. One magnificent curvilinear fault maintains an almost constant downthrow of 100-125m along a horizontal distance of 30Km, forming a very sharp, steep scarp.

The Wonji Fault Belt continues from Wonji north across the Awash basin, where fumarolic activity is associated with faults cutting river alluvium, to Mt. Boseti Guda, a denuded silicic pile encircled by a remarkable ring-fault up which very fresh scoriaceous olivine basalts have ascended. Farther north large areas of such basalts, dated at about 150 years old, have been extruded from fault-fissures and lava cones, and at Gariboldi Pass are associated with surface cauldron subsidence (Mohr 1961B). Thence the behaviour of the Wonji Fault Belt is uncertain, but probably extends via Fantale, a large dormant hyperalkaline silicic volcano from whose south-east flanks fresh basalts have been erupted (see Mohr 1961B), before possibly bifurcating into southern Afar, or else continuing via the Lake Abbe basin to the Gulf of Tajura.

Very little is known of the faulting of internal Afar. For southern Afar the most reliable data are those of Gortani (1952) which indicate that important N.-S. faults run along the eastern margin of the middle Awash valley from Gawani to Tiho. The direction of downthrow is not given. Between Tiho and Lake Abbe the faults tend to be orientated N.E.-S.W., related to faulting of the Main Ethiopian Rift, but in the Lake Abbe basin itself strong N.W.-S.E. faults related to the faulting of the Gubet Kharab and Lake Assal basins determine the local morphology. These N.W.-S.E. faults continue with complex bifurcations and dyings-out past Sardo and Tandaho. An abrupt change of orientation of faulting in southern Afar seems therefore to occur along a line extending roughly from Lake Abbe to Miesso, that is, parallel and somewhat to the east of the Herali stream. West of this line the faults run N.E.-S.W. and N.-S. (East African trend), whereas to the east they run between E.-W. and N.W.-S.E. (Gulf of Aden and Red Sea trends).

Even less is known of the faulting in northern Afar, except that the dominant tectonic trend is N.-S. and N.N.W.-S.S.E. as manifested by the huge fault-fissures south-west of Lake Afrera, and by the boundaries of the Salt Plain. (But see note at beginning of section X.)

Recent vulcanicity and seismicity has been plentiful in Afar, and a number of volcanoes are active there today. In southern Afar Dainelli (1943) considers to recognize two alignments of volcanic centres. The first, trending between N.E.-S.W., includes, from north to south:

Mussa Ali, Mel-ale, Didoli, Kurub, Borauli, Gabillema, Wolkili,
As-boru, Langudi, Ayelu and Amoissa, Dabita-ale, Dofane, and Fantale.

The second alignment, less well developed and trending approximately E.N.E.-W.S.W., includes, from east to west:

Mt. Elmis, Gara Borat, Foldi, Cadda Rugdaya, Afdem, Assabot, and Fantale, where it meets with the first alignment. It is notable that Fantale is the region where the Wonji Fault Belt becomes obscure and appears to bifurcate. Many of the volcanic cones listed above are associated with small patches of fresh basalts and with active fumaroles, especially those of the first-mentioned alignment.

In northern Afar extensive recent volcanic activity has been centred about Lake Afrera, whose shores are flanked by the centres of Afrera (extinct), Amarti, Borauli, Coh-mara and Tindaho. To the south-west of Lake Afrera the plains of Afar are covered eastwards from the base of the Ethiopian Plateau with thousands of sq.Km of fresh, scoriaceous flood olivine-basalts which have flowed north-eastwards from N.-S. fault fissures. West of Lake Afrera runs the important N.N.W.-S.S.E. line of volcanoes comprising the active Erta-ale chain which overlooks the Salt Plain to the east. From south to north the volcanoes of this chain are Ummuna, Erta-ale, Gabuli, Alu, and Kebrit-ale. Erta-ale was observed in eruption by the author in 1960, the crater being filled with red-hot pasty basalt from the centre of which projected a small cone of sulphur-rich material; a huge cloud of steam was rising from the crater, and extremely fresh, steaming basalt flows had emerged from radial fissures on both the north and south flanks of the main cone. East of Lake Afrera lies the large volcano of Afdera which erupted in 1907. Farther east, at the southern end of the Danakil Alps, numerous centres are associated with the Dubbi volcanic field from which there were violent eruptions in 1861.

Near the French Somaliland border with Eritrea the large basaltic pile of Mussa Ali has sent older, Pleistocene flows north to Assab and south to near the Gulf of Tajura, all these flows now being gently tilted down to the north and proving a posterior uplift of at least 400m in the Gulf of Tajura region(see Voute 1959 and Dainelli 1943).

North of the Salt Plain numerous smaller volcanic centres are situated in the Gulf of Zula region, of which special mention may be made of the dormant volcanoes Alid, Elelali (Jalua), and Amoer-ale. All of these volcanoes have had a late basaltic phases superimposed upon an earlier silicic lava phase, a characteristic of so many of the volcanoes of the Ethiopian Rift System.

The most northerly occurrence of the Aden Volcanic Series basalts of the Ethiopian Rift System is a small patch on the Red Sea coastal plain south of the Lebca valley in Eritrea, at latitude 15.55N.

X. The Origin of the Ethiopian Rift System

In view of requests made to the author it has been decided to add a section concerning the possible origin of the Ethiopian Rift System, and the mechanism by which it has come to its present form. This topic, which had been deliberately omitted from this paper as originally planned, is only included here with the understanding that the most probable theory of origin of the Rift System is given; a theory which will certainly undergo many modifications in the light of future geophysical and geochemical research. In this respect information of considerable importance has been obtained from a very recent (Feb. 1962) expedition made by P. Gouin and the author to the southern regions of the Salt Plain of Afar: the detailed observations on gravity, magnetic dip, and geology will be published in a future issue of this Bulletin, but some general observations are included in the following text.

Two major tectonic events preceded the formation of the Rift System in Ethiopia:

1. Folding, compression, metamorphism, foliation and lineation of pre-Cambrian geosynclinal sediments during at least two periods in the pre-Cambrian, along trends lying between N.-S. and N.E.-S.W. (See Fig.4). As in East and Central Africa, these ancient pre-Cambrian tectonic trends have largely determined the directions of the Cainozoic rift-faulting, though in Ethiopia there still remains an almost complete lack of detailed mapping and study of the Basement Complex. It should be noted that the natures of the two movements were quite different, that of the pre-Cambrian being orogenic whereas that of the Cainozoic was normal rifting (see below).

2. The uplift of the Arabo-Ethiopian swell which immediately preceded the rifting. Its nature has been described in section VII of this paper in which its intimacy with the Rift System has been emphasised. Through lack of relevant data the problem of the cause of this uplift has generally been neglected by Rift geologists, and justifiably so at their time of writing. However, with the rapid increase in knowledge during the last decade in the fields of mineral and rock thermodynamics and in geophysical interpretation of the structure of the Earth's crust and upper mantle, some useful hypotheses have now been put forward.

As early as 1936 Willis attempted to explain the uplift as being due to underlying melting of the lower crust by accumulated radioactive heat such that granitic magma was formed. This melting of supposed granitic material would be accompanied by expansion which would naturally act in an upwards direction. Willis' theory is not now accepted, there being no reason why heat should have accumulated in the crust more strongly beneath the eastern part of the Arabo-African continent than elsewhere where there has been no uplift. More pertinently, the petrology and geochemistry of the lavas of the Rift System and associated volcanics is completely at variance with the underlying presence of granitic magma, the parent magma in the Horn of Africa being an alkaline and volatile-rich olivine basalt. Granitic magmas are almost entirely limited to orogenic environments.

Quennell (1960) has, on the theoretical evidence of other workers, suggested that a phase change from eclogite to basalt has occurred at the base of the crust underlying the present Rift System, the resultant decrease in density accounting for the uplift of the overlying lithosphere. Moreover, the liquid basalt, presumably melted by radiogenic heat, would provide an immense reservoir of magma which could have supplied the great quantity of Tertiary flood basalt flows observed in Ethiopia. Wetherill (1961) discusses the theoretical function of temperature with depth for a steady-state crust and finds that, for the continental crust at least, the M-discontinuity could well represent a phase transition; the depth of this transition would be temperature dependant, with concomittant influence on isostasy which, in the case of higher temperature and heat flow than normal, would result in uplift of the overlying lithosphere.

Harris and Rowell (1960), however, dispute upon the basis of geochemical evidence that the M-discontinuity can represent an eclogite-basalt phase-transition. Rather, the chemistry of lavas might suggest that the M-discontinuity marks the boundary between crustal basaltic rocks and the peridotitic mantle beneath. This is the classical geological interpretation, in support of which it must be admitted that the new arguments of Harris and Rowell are not altogether conclusive. Thus they consider basaltic magmas to be derived from the peridotitic mantle by partial fusion processes, and similarly they consider that granite can be the result of partial fusion of basaltic and other sub-silicic rocks rather than due to differentiation. Certainly partial fusion of any rock results in the formation of a more silicic liquid than would result from complete fusion; thus peridotite could give rise to basaltic magma. But whether this process could allow of the observed extraordinary uniformity of composition of flood basalts is difficult to concede. Harris and Rowell do indeed state that if the M-discontinuity represents purely a basalt-eclogite phase transition then eclogite (S.G. 3.5) would be resting on peridotite-dunite (S.G. 3.3) of the middle mantle, but that this in turn would be a very convenient position for the proponents of mantle convection currents. However, on the basis of mineral stabilities under temperature and pressure Harris and Rowell show that a phase transition M-discontinuity cannot be held as other than a very dubious hypothesis at the present state of knowledge.

As regards the uplift of the Arabo-Ethiopian swell, the phase-transition causal theory is not excluded even though the M-discontinuity is proven not to be an eclogite-basalt mineral transition, as such a transition could well occur at a lower level within the mantle, perhaps at the minor seismic discontinuity at 900km. depth.

In none of the theories of uplift being due to sub-crustal phase-transition is the site of the uplift, fundamentally one of abnormally high heat-flow, explained, but this a recent article by Menard (1961) on the East Pacific Rise has attempted to do. Menard describes the East Pacific Rise, a long broad ridge running approximately due south from California for a distance of 15,000km with a width of 2000-4500km, as a region of high seismic activity and of abnormally high heat flow from the interior (though on the flanks of the Rise the heat flow is lower than normal); this parallels the Ethiopian Rift System, aligned along the crest of the Arabo-Ethiopian swell, which also is a region of active seismicity and high heat flow. Again, the crest of the East Pacific Rise is marked by a wide zone where the crust is significantly thinner than normal, and is furthermore marked by longitudinal block-faulting similar to rift-type faulting. Earthquake shear wave velocities are appreciably slower than normal through the crust beneath the Rise; similar slow velocities are obtained for local quakes in Ethiopia (Gouin 1962).

These various properties of the East Pacific Rise are explained, Menard proposes, by presuming two parallel, oppositely rotating convection cells in the upper mantle to lie beneath the crest of the Rise. Due to this convective flow the crust is bulged up, cracking open along the crest and also splitting along huge observed transverse tear-faults, enabling areas of the crust to be moved away from the crest by frictional pull from the convection flow. (Note: these linear tear-faults of the East Pacific Rise are not paralleled in the African Rift System, though transverse tectonic alignments occur in the Kilimanjaro-Meru volcanic line, the Mufumbiro volcanic line, the eastwards displacements of the southern units of the Ethiopian Rift System, the Chilalo-Wachacha displacements, and others; in none of these cases, however, is there any clear evidence of post pre-Cambrian tear-faulting). Along the crest of the East Pacific Rise the crust has been thinned by a horizontal stretching estimated by Menard to total 600km.

At the present state of knowledge of the crustal and sub-crustal structure of the Arabo-Ethiopian swell, where there are virtually no concrete data available, it is valueless to speculate on the detailed causal history of the swell. On the other hand, the surficial data known for the Ethiopian Rift System, together with the data on the ocean swells (or ridges), permit a tentative suggestion as to the cause itself of the Arabo-Ethiopian swell to be given, if only to direct future research.

The crest of the Arabo-Ethiopian swell, traversed by the Rift System (though not in precise alignment in the Lake Margherita region) is marked by high seismicity, high heat flow, active vulcanicity, and low shear-wave sub-crustal velocities. The thickness of the lithosphere along the crest of this swell is not known but is the subject of present research at this institution; certainly it has been easily fractured and has permitted the ascent of flood basalts in enormous quantities during the Oligo-Miocene, together with later interbedded extrusions of hyperalkaline silicics. These silicic lavas seem to have originated from fractionation in a static basaltic magma; if they had resulted from partial fusion of less silicic rocks they would have appeared early in the sequence of the Trap Series. The presence of carbonatitic magma products associated with the Ethiopian Rift System also indicates special differentiation from a basic or perhaps ultrabasic magma. The latest phase of vulcanicity, still continuing, has been one of renewed basalt extrusion both in the Rift and the Ethiopian Plateau, but in much smaller quantities and with a much higher volatile content than during the Oligocene.

The sub-crustal portion of the Arabo-Ethiopian swell can therefore be considered to be largely occupied by basaltic rocks beneath a thin crust of silicic pre-Cambrian Basement, the upper portion of the basaltic interior having undergone periods of temporary fusion. These basaltic rocks are now exposed virtually in situ along the bottom of the complex trough of the Red Sea. The depth and form of the M-discontinuity below the Arabo-Ethiopian swell is not yet known, but it is probable that a phase-transition basalt-eclogite occurs at some depth below this discontinuity, and that accumulation of excessive radiogenic heat above the transition line has lowered the boundary and thus caused isostatic raising of the lithosphere. According to this theory the Arabo-Ethiopian swell should be in isostatic equilibrium with the adjoining plains of Sudan to the west. As is shown below, this theory also requires that the Rift System itself should be in isostatic equilibrium with the adjoining horsts. That excessive radiogenic heat should have accumulated under the eastern side of the African continent, along the line of the resultant swell, could be related to the fact that this regional belt was one of intense pre-Cambrian orogenic activity, with a resultant thickening of the radioelement-rich granitic crust; other factors must enter, however, as the tremendous and as yet unexplained shear movements and accompanying cataclasis of the Basement in the present-day Lake Nyasa and Lake Rukwa rifts indicates. (Brown 1961).

The presence of convective cells in the mantle beneath the Arabo-Ethiopian swell remains speculative, but if they be proven present the author would consider them to be merely the results of, rather than the cause of, phase-transition changes. The occurrence of the Sudan boundary fault-zone and the Somalia coastal fault-zone (map 1), regions urgently requiring geophysical study, cannot be divorced from a consideration of the swell uplift, indicating either abrupt margins to the zone of phase-transition change and causing fracturing of the overlying rigid crust, or the presence of strong downward convective currents just outside these fault-zones, or some unknown factors. The alignment of these two great fault-zones delineates the width of occurrence of the whole Rift System in the African continent.

The complex plan of the Ethiopian Rift System, where three units of rifting converge and of which two units show abnormal development, cannot at present be causally explained. It can be noted, however, that the three trends do not intersect but adapt themselves to each other in a flexible manner in the region of Afar, except perhaps for the most recent (Quaternary) movements.

If the fundamental explanation of the geographical plan of the Ethiopian Rift System cannot yet be ascertained, yet the details of that system are of great interest and call for further comment.

Firstly, the mechanism of rifting itself, variously ascribed to horizontal tension or horizontal compression or to direct vertical pressures according to different earlier theories, is now generally accepted to be due to horizontal tension forces. This, certainly accords with the idea of an uplifted and stretched crust, rifting tending to coincide with the crest, that is, the line of maximum strain. However, it must be emphasised that rifting does not necessarily, nor even likely, imply a collapsing and sinking of the crest but merely the formation of associated horsts and troughs such that isostasy is maintained. Of the various hypotheses of continental rift mechanism discussed by the author in Mohr (1962), the most plausible is that of Heiskanen and Meinesz (1958, Chapter 10D)* which is summarised as follows:

Assuming an elastically deforming crust lying above a plastic sub-stratum and assuming that the stresses in the crust do not exceed the limits of elasticity, then mathematical treatment can reveal the behaviour of the crust under tension from an uplifted swell.

The first stage is the development of a fault-plane fracture in the crust, and this is tilted where, as in the lithosphere, density increases with depth. The angle of dip of this fracture can be calculated theoretically to be about 63°, in agreement with observations in the Ethiopian Rift System, where, however, the dips are not infrequently steeper.

* Note: the problem of the origin of oceanic rifts is less easily solved. Thus the plausible explicatory diagrams of Menard (1961) fail to show the true horizontal scale of these rifts.

Separation under further tension results in one side of the faulted crust bending upwards, and the other side downwards, in order to restore isostasy. Still further tension causes new fault planes to develop at the point of maximum curvature, and therefore maximum tensile strain, within the downwarped side of the fractured crust. A graben thus results with overlooking uplifted and upwarped rims. Note that fracturing is less likely to occur in the upwarped side of a singly fractured crust owing to its being compressed at the surface rather than stretched, whilst at the base of the crust considerable hydrostatic stress makes fracture here even less likely. On the other hand the occurrence of horsts within the Ethiopian System proves that such fracturing can occur under certain favourable conditions, usually associated with complex and intense normal graben formation. This treatment of Heiskanen and Meinesz thus explains the existence of horsts as well as graben as being due solely to isostatic readjustment, without invoking compressional forces. As will be seen, all important features of the Ethiopian Rift System can be explained as due to isostatic readjustment forces.

Heiskanen and Meinesz' mathematical treatment of such crustal fracturing yields data of 63km for the graben width and 1540m. for the graben depth. The latter figure is composed of 860m. absolute subsidence of the rift floor and 680m uplift of the plateaux edges, using a 63°dip angle for the boundary faults. All these data are in good general agreement with observations in Ethiopia. If a zone rather than a plane of weakness exists in the strained crust then numerous fractures could form during the first stage of tension, producing a number of parallel faults closely separated, and with identical directions of downthrow when increasing tension permitted movement along the fractures. It is possible that the Wonji Fault Belt of the Main Ethiopian Rift floor has its origin in this way, though its high seismicity and associated volcanic activity make it doubtful that its development is yet completed.

If, as the above theory presumes, the Rift System is in isostasy then the existence of negative gravity anomalies over the African rifts must be explained. On the old compression hypothesis this was easy enough, sub-crustal forces holding down the central faulted block which could not rise under isostasy until the compression was released. But where tensional forces are invoked for rift-faulting, then theoretically there is nothing to prevent restoration of isostasy wherever this may have been disturbed. (According to the Heiskanen-Meinesz theory isostasy is not disturbed by rift-formation, and in fact is the cause of it). It is now held that the negative gravity anomalies over the rifts are not crustal in origin, but are due to surficial accumulation of light sediments in the graben, naturally regions of rapid sedimentation. Heiskanen and Meinesz calculate that a layer of sediments 1.4km thick, with a density of 2.50 gm/cc., would cause a further 1.1km subsidence of a freely moving central block, and would give mass-deficiencies in agreement with those interpreted from gravity observations (about -50 m.gals in East Africa: values obtained by P. Gouin for the Main Ethiopian Rift and for Afar will be published in the near future.)

The Rift System, therefore, is best explained as the result of fracturing of the lithosphere under tension from an uplifting sub-crust, the fractured blocks being free to move under isostatic readjustment forces.

When applied to the details of the Ethiopian Rift System, however, there are numerous features requiring a much more extended treatment of the Heiskanen-Meinesz theory of rifting.

In Ethiopia pronounced upwarping of the plateaux margins overlooking the graben has only been found in the Guraghe Mts horst. Very gentle upwarps are present along the eastern boundary of the Ethiopian Plateau overlooking Afar, and it may be that here denudational recession has removed the more steeply upwarped margins, or that vulcanicity closely contemporaneous with the rifting has generally obscured such a phenomenon, as in northern Shoa. In southern Eritrea, on the contrary, the marginal zone of the Ethiopian Plateau is downwarped towards the Afar depression but this is abnormal.

The general development found along the marginal zone of the Ethiopian Plateau and Afar, lying especially between the original boundary faults and the denudational scarp further west, is one of fresh faulting downthrown west with a tendency to develop into small true graben in the cases of the Borkenna valley and its northwards extension via the Lakes Ardibbo and Haik basins, the Guf Guf valley, the Dergaha valley of southern Tigrai, the unnamed valley west of Lake Assale whose stream flows north into the Endeli river, and perhaps the Comayli river valley. The author has made a special study of the Borkenna graben, where

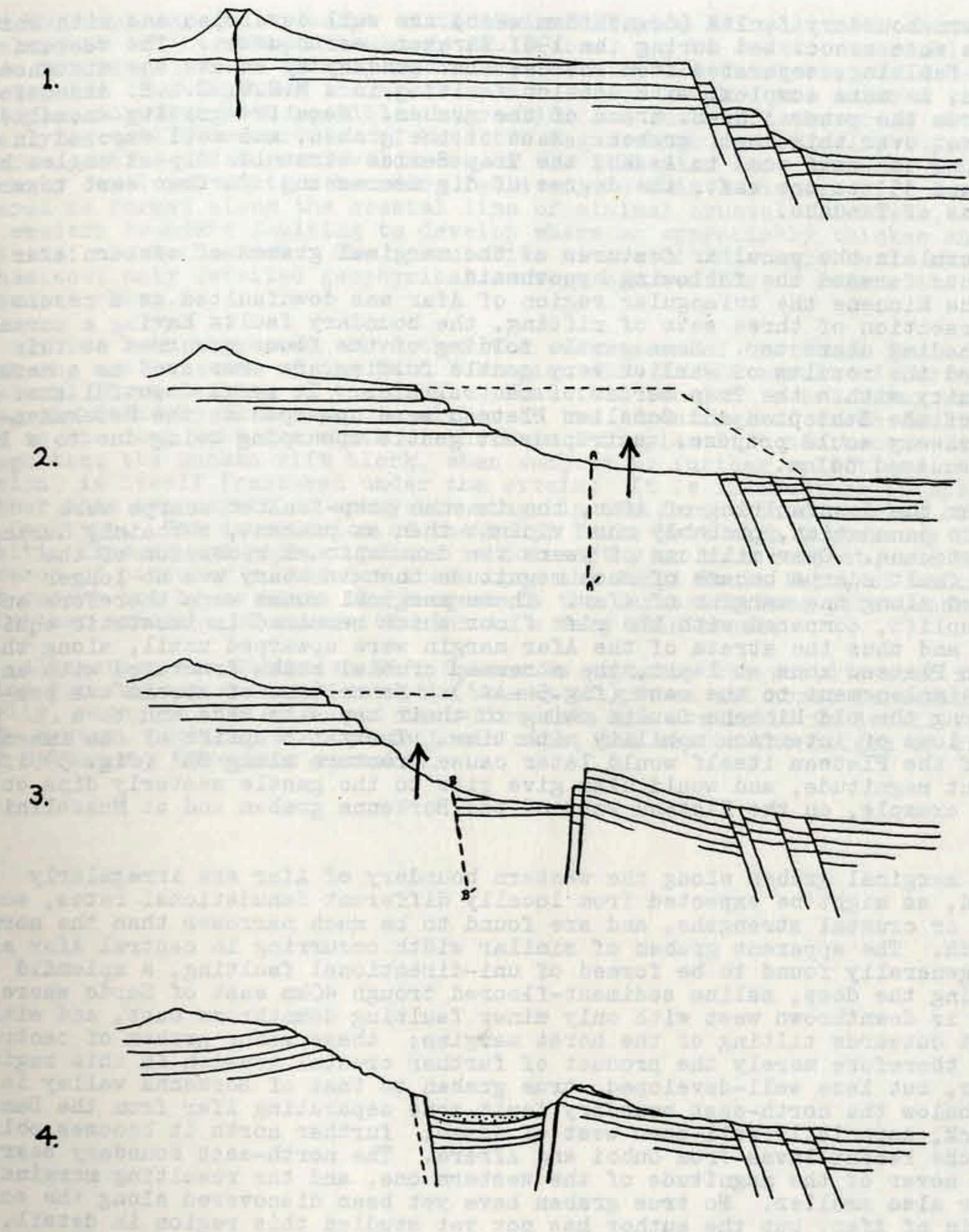


Fig. 5. Stages in the development of the Borkenna graben.

1. Main Miocene post-Trappean rifting
2. Denudation proceeds and isostatic crustal strain develops
3. Isostatic readjustment causes fracturing along AA' (exampled in the present-day Guf Guf valley.)
4. Further readjustment causes fracturing along BB' (exampled in the present-day Borkenna valley.)

(vertical scale greatly exaggerated)

the eastern boundary faults (downthrown west) are well developed and with which movements were associated during the 1961 Karakore earthquakes. The western boundary faulting, separated from the eastern boundary by an average distance of about 4km, is more complex, with echelon faulting in a N.N.W.-S.S.E. direction offset from the general N.-S. trend of the graben. Negative gravity anomalies are present over this small graben. East of the graben, and well exposed in the hills along the main road to Assab, the Trap Series stratoids dip at angles between 25 and 35° to the east, the degree of dip decreasing further east towards the plains of Tandaho.

To explain the peculiar features of the marginal graben of western Afar the author puts forward the following hypothesis:
During the Miocene the triangular region of Afar was downfaulted as a result of the intersection of three sets of rifting, the boundary faults having a normal steeply hading character. Some gentle folding of the floor occurred at this time, and indeed the results of earlier very gentle folding are preserved as a marked unconformity within the Trap Series of central Afar. It seems doubtful that the margins of the Ethiopian and Somalian Plateau were upwarped as the Heiskanen-Meinesz theory would propose, their present gentle upwarping being due to a later cause discussed below.

After the downfaulting of Afar, the immense step-faulted scarps were subject to denudation, probably more violent than at present, certainly during the Pleistocene. Over millions of years the denudational recession of the original fault scarps became of such magnitude that isostasy was no longer maintained along the margins of Afar. These marginal zones were therefore subject to uplift, compared with the rift floor which remained in isostatic equilibrium, and thus the strata of the Afar margin were upwarped until, along the Ethiopian Plateau zone at least, the stressed crustal rocks fractured with an upwards displacement to the east (fig.5 -AA'). No release of strain was possible along the old Miocene faults owing to their opposite hade and to a probable loss of interface mobility with time. Isostatic uplift of the immediate margin of the Plateau itself would later cause fracture along BB' (fig. 5) if of sufficient magnitude, and would also give rise to the gentle westerly dips observed, for example, on the Plateau west of the Borkenna graben and at Mussolini Pass.

The marginal graben along the western boundary of Afar are irregularly developed, as might be expected from locally different denudational rates, scarp heights, or crustal strengths, and are found to be much narrower than the normal rift width. The apparent graben of similar width occurring in central Afar are in fact generally found to be formed of uni-directional faulting, a splendid example being the deep, saline sediment-floored trough 40km east of Sardo where the faulting is downthrown west with only minor faulting downthrown east, and with prominent outwards tilting of the horst margins; these minor graben of central Afar are therefore merely the product of further crustal tension in this region. A similar, but less well-developed, true graben to that of Borkenna valley is present below the north-east boundary fault zone separating Afar from the Danakil Alps block, especially well-seen west of Assab; further north it becomes obliterated by the recent lavas from Dubbi and Afrera. The north-east boundary scarp of Afar was never of the magnitude of the western one, and the resulting marginal graben is also smaller. No true graben have yet been discovered along the southern margin of Afar, but the author has not yet studied this region in detail.

According to the above hypothesis the warping of the strata along the boundary regions of Afar is a phenomenon not contemporaneous with the rift-faulting, but considerably post-dating it, and can be the cause of earthquakes whose character should be different from those resulting from continuing tensional movements. It is probable that upwarping to the immediate east of the marginal graben of Afar has largely been matched by lowering due to denudation, especially during the pluvial periods; thus today the hills east of the Borkenna graben present an extremely dissected aspect, and the eastern boundary faults AA' (fig.5) are frequently apparently less well preserved than the western boundary faults BB'. The lack of even secondary volcanic phenomena associated with the marginal Afar graben, phenomena so common in central Afar, is further proof of a purely isostatic origin for these graben.

The marginal rifts of Afar die out as the Main Ethiopian Rift is approached to the south. The faulting of the Main Ethiopian Rift is more recent than that of Afar, and the denudational recession of the fault scarps along the Rift has been much less. Also the Main Ethiopian Rift is undoubtedly too narrow for such isostatic processes to occur such as have taken place in Afar, though this Rift is appreciably wider than the Gregory Rift of Kenya. This greater distance between the opposing fault scarps of the Main Ethiopian Rift, as well as the poor development of the western boundary fault zone, may be due to a variable transverse thickness of the underlying crust; the variable thickness could be due to the tension deriving from the swell uplift, which reached its maximum values in Ethiopia, together with possible interaction and fusion of the crust with the underlying shallow reservoirs of basaltic magma which periodically supply the numerous active and dormant volcanoes of the Ethiopian Rift System. Thus the strongly developed eastern boundary fault of the Main Ethiopian Rift can be considered as formed along the crestal line of minimal crustal thickness, leaving the western boundary faulting to develop where an appreciably thicker and more resistant crust obtained. The speculative nature of this hypothesis must be emphasised; only detailed geophysical surveys can confirm or refute the ideas presented above.

It has been suggested above that the occurrence of the Wonji Fault Belt along the central zone of the Main Ethiopian Rift is the result of further tensional forces acting on the crust. That this tension is not being relieved along the boundary faults points either to the 'freezing' of these faults, or else to the fact that the width of the Main Ethiopian Rift has become large enough that the sunken rift block, when subject to further uplift and resulting tension, is itself fractured under the strain. It is interesting to speculate whether this represents an embryonic stage in the formation of a rift of the Red Sea type. The association of the Wonji Fault Belt with Quaternary flood basaltic fissure and pipe eruptions is noteworthy in this respect, and the occurrence of circular subsidence areas upon the Wonji Fault Belt, of which the most recent but by no means the largest is the Gariboldi Pass pair (Mohr 1961 B), is further evidence of severe tension in a very thin crust.

Altogether the Ethiopian Rift System is probably the world's most fruitful region for further research into the causes of graben and horst formation. When gravity, magnetic, seismic, and heat-flow data are available in detail for the whole system, together with geotectonic maps, the key to the origin of the whole Rift System may have been revealed.

Acknowledgments The author's grateful thanks are due to Dr. Lucien Matte, President of the University College of Addis Ababa, and to Pierre Gouin, Director of the Geophysical Observatory of Addis Ababa, for innumerable assistances which have made this paper possible. Also to General Assefa, Commanding Officer of the Imperial Ethiopian Air Force, for making flights available over the less hospitable regions of Afar, and to the Imperial Highway Authority for the loan of aerial photographs.

XI. Gazeteer of Place-Names Mentioned in the Text.

(Note: Until an accurate geodetic survey of Ethiopia is made the figures given below cannot be considered as more than approximate.

All data for longitude are East and for latitude are North.

For rivers the position of their effluence is given).

Lat.	Long.	
11.13	34.58	Abbai, river
11.10	41.45	Abbe, Lake
10.32	39.48	Abuya Mieda, Mt.
7.38	38.35	Abyata, Lake
8.32	39.16	Adama (Nazareth)
9.02	38.45	Addis Ababa
13.48	39.43	Adgu, Mt.
14.16	39.27	Adigrat
14.10	38.54	Adua
9.30	40.51	Afdem, Mt.
13.14	41.25	Afdera, Mt.
13.18	41.02	Afrera, Lake
13.12	41.00	Afrera, Mt.
10.45	42.35	Aisha
12.58	39.32	Alaji, Amba
5.38	38.14	Alghe (Agheremariam)
14.53	39.55	Alid, Mt.
15.16	39.42	Alighede, river
13.49	40.22	Alu, Mt.
7.46	38.47	Alutu, Mt.
5.50	37.56	Amaro, Mts.
13.20	41.08	Amarti, Mt.
8.07	38.16	Amba, Mt.
14.08	37.19	Amba Bircutan
8.57	37.57	Ambo
15.08	39.52	Amoer-ale, Mt.
10.04	40.50	Amoissa, Mt.
11.13	39.44	Ardibbo, Lake
10.50	41.20	As-boru, Mt.
7.58	39.07	Aselle
12.35	39.32	Ashangi, Lake
14.27	39.37	Asimba, Mt.
15.20	38.55	Asmara
13.01	42.43	Assab
9.16	40.34	Assabot, Mt.
11.40	42.25	Assal, Lake
14.07	40.21	Assale, Lake
7.03	38.27	Awasa, Lake
11.10	41.39	Awash, river
9.00	40.10	Awash Station
14.07	38.42	Axum
10.05	40.42	Ayelu, Mt.
7.55	39.24	Badda, Mt.
11.35	37.25	Bahar Dar
17.19	37.31	Baraka, river
10.15	34.45	Beni Shangul
10.23	42.33	Bio Caboba
8.44	38.59	Bishoftu (Debra Zeit)
8.53	39.17	Bokam, Mt.
9.45	41.39	Borat, Gara
13.15	41.08	Borauli, Mt.(Tigrai)
11.38	41.26	Borauli, Mt.(Wallo)
10.37	40.28	Borkenna, river
8.33	39.28	Boseti Guda, Mt.
10.43	37.07	Burie
5.23	37.50	Burji
9.41	41.03	Cadda Rugdaya, Mt.
5.50	37.40	Chamo, Lake

Lat.	Long.	
7.55	39.13	Chilalo, Mt.
7.10	38.27	Chubbi, Mt.
13.22	40.59	Coh-mara, Mt.
15.13	39.41	Comayli, river
11.04	39.43	Combolcha
9.02	36.08	Dabana, river
9.44	40.16	Dabita-ale, Mt.
11.17	36.55	Danghila
11.02	42.38	Dawanle
9.50	39.47	Debra Sina
5.50	37.56	Delo, Mt.
10.06	35.38	Didessa, river
12.28	41.33	Didoli, Mt.
6.25	38.18	Dilla
9.35	41.52	Dire Dawa
9.19	40.05	Dofane Mt.
13.31	41.52	Dubbi, Mt.
10.34	34.24	Dul
13.57	41.38	Ed
15.02	39.49	Elelali, Mt.
10.23	44.16	Elmis, Mt.
4.13	38.23	El Sod
13.40	40.35	Erta-ale, Mt.
8.58	39.54	Fant-ale, Mt.
4.30	38.12	Fulli, Gara
8.53	38.42	Furi, Mt.
11.04	41.16	Gabillema, Mt.
13.47	40.26	Gabuli, Mt.
6.43	38.15	Gado
12.57	36.09	Galabat
6.10	37.54	Galana-Dullei,river
6.44	38.39	Garamba, Mt.
8.48	39.42	Gariboldi Pass
15.14	36.32	Gash, river
10.10	40.38	Gawani
8.49	40.31	Ghelemso
10.04	42.52	Gokti
12.15	37.17	Gorgora
11.49	51.17	Guardafui, Cape
11.30	42.30	Gubet Kharab
12.40	39.42	Guf Guf, river
6.13	37.24	Gughe, Mts
8.19	39.58	Gugu, Mt.
8.17	38.23	Guraghe, Mts
15.15	39.51	Haddas Shaghede, river
11.19	39.42	Haik, Lake
11.55	42.15	Halol, Lake
9.18	42.08	Harar
10.25	41.10	Herali, river
15.41	38.46	Ira, Mt.
11.35	36.56	Ismala Georgis
5.47	38.12	Jabasire, Mt.
9.49	39.40	Jib Washa, Mt.
9.20	42.47	Jijiga
7.40	36.50	Jimma
7.22	39.09	Kakka, Mt.
10.31	39.54	Karakore
15.28	36.24	Kassala

9.13	40.06	Kassam river
13.55	40.15	Kebrit-ale, Mt.
6.43	38.08	Kiraka, Mt.
8.27	39.06	Koka
7.18	38.07	Kolito
2.43	36.55	Kulal, Mt.
10.43	36.15	Kumbari
11.36	41.10	Kurub, Mt.
7.35	38.45	Langano, Lake
17.43	37.28	Langeb, river
10.33	41.02	Langudi, Mt.
16.11	39.15	Lebca, river
2.17	36.34	Likaiyu, Mt.
2.20	36.15	Loriyu Plateau
12.47	39.33	Mai Chew
10.44	39.50	Majite
13.31	39.28	Makalle
8.04	38.50	Maki, river
6.25	38.00	Margherita, Lake
15.46	39.36	Massawa
4.05	38.19	Mega
9.15	39.31	Meghezez, Mt.
12.38	41.35	Mel-ale, Mt.
9.39	39.48	Membret, Mt.
9.15	40.45	Miesso
8.36	39.07	Mojjo
3.32	39.03	Moyale
9.15	41.43	Mullata, Mt.
12.28	42.25	Mussa Ali, Mt.
9.51	39.45	Mussolini Pass (Termaber)
7.20	38.42	Neghelle
5.20	39.35	Neghelli
2.09	36.49	Nyiru, Mt.

4.35	36.04	Omo, river
12.30	39.32	Quoram
4.00	36.00	Rudolf, Lake
11.52	39.26	Santara, Mt.
11.58	41.18	Sardo
12.41	39.30	Sarenga, Mt.
14.42	39.25	Senafe
7.28	38.30	Shala, Lake
7.12	38.36	Shashamanne
10.45	47.18	Shimber-Berris, Mt.
7.01	35.50	Shoa Ghimira
8.18	39.29	Sire
14.16	39.48	Sobni, Mt.
4.40	36.52	Stefanie, Lake
14.44	39.32	Swera, Mt.
12.00	37.20	Tana, Lake
11.41	40.57	Tandaho
11.40	43.00	Tajura, Gulf of
2.22	36.37	Teleki, Mt.
11.03	40.42	Tiho
13.21	41.02	Tindaho, Mt.
9.13	41.19	Tita, Mt.
8.53	34.50	Tulu Walel
13.32	40.37	Ummuna, Mt.
8.58	38.37	Wachacha, Mt.
11.48	39.35	Waldia
1.45	44.30	Webi Shebeli, river
6.36	38.25	Wondo
8.20	39.15	Wonji
9.44	39.45	Woti, Mt.
4.54	38.06	Yavello
8.54	38.57	Yerer, Mt.
15.25	39.40	Zula, Gulf of
8.00	38.50	Zwai, Lake

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SEISMOLOGICAL R

JANUARY - JUNE 196

PIERRE GOUIN

The Seismological Station

Site	:	University College compound, Addis Ababa
Geographical coordinates	:	North 09° 01' 45" East 38° 45' 56"
Lithologic foundation	:	Stratoid olivine basalts of the Tertiary Trap Series
Elevation	:	2242.5 meters

Instruments:

Until February 15,1960 : Z = SP Willmore of T_o = 1 second, T_G = 2 seconds; EW= LP electromagnetic of T_o = 6 seconds, T_G = 8 seconds

From February 15 unwards: - Three identical Willmore seismometers were used coupled to the following galvanometers:

Z T_G = 2 seconds
EW T_G = 21 seconds
NS T_G = 21 seconds

- Recording time base : 30 mm / minute

- The time marks are from a Riefler invar pendulum compensated for pressure variations. It is controlled by radio daily.

Reduction of the Seismograms

Long distance quakes

Unless otherwise stated, for the interpretation of the long distance quakes, the times of origin and the epicenters are taken from the USC&GS.An asterisk after the time of origin indicates that the value is from the BCIS.

Local quakes

In the case of local tremors, d* indicates the approximate hypocentral distance in kilometers. The Travel Times used are Joliat's Tables (Saint Louis University, 1931) postulating the following velocities:

Pn = 7.8 km / sec.	Sn = 4.35 km / sec.
P* = 6.3 km / sec.	S* = 3.7 km / sec.
Pg = 5.4 km / sec.	Sg = 3.3 km / sec.

In the light of recent records from the tremors in French Somaliland (Dec. 1959 and Jan. 1960) and from the Kara Kore quakes (Ethiopia, May to Sept. 1961),it was found that Joliat's Tables give an epicentral value 5 - 10% consistantly higher than expected. Until sufficient statistical data permit a sound readjustment of these velocities for Ethiopia, the above values will continue to be used.

No.	DATE	ORIGIN TIME U.T.	PHASES		Lat.	Long.	h (km)	d° (km)	Location & Remarks
1	2/1	05-06-54	eP	05-16-55	2½N	96E			coast of Sumatra.
2	2/1	12-21-51	iP	12-33-23	56S	2W			S. of Bouvet Is.
			S	43-10					
3	2/1	14-41-35*	eP	14-46-55	25¾N	55E			S. Persian Gulf.
4	2/1	23-08-30*	eP	23-18-22	4½N	97E			Sumatra.
5	3/1		P,	00-05-41				190km.	
			S,	06-03					
6	3/1		P,	00-21-(39)				175km.	
			S,	-59					
7	3/1	11-24-00	iP	11-33-21	44N	84½E			Sinkiang, China.
8	3/1	20-19-30	iP	20-26-20	39½N	15½E	250km.		Tyrrhenian Sea.
			i	27-17					
9	4/1	06-07-48*	iP	06-08-56					foreshock, French-
			M	13-30					Somaliland. (felt)
10	4/1	06-16-35	iP	06-17-44				500km.	French Somaliland. (damage at Aita;
			M	19-30					felt in Tajura, Ali Sabieh, Djibouti)
11	4/1	(06-35-09)	iP	06-36-23				640km.	off coast of French Somaliland.
			S	37-305					
			M	39-16					
12	4/1		eP	07-02-(42)				590km.	Somaliland.
			S	03-45					
13	4/1		eP	07-14-14				615km.	Somaliland.
			S	15-21					
14	4/1		iP	07-26-09				575km.	Somaliland.
			S	27-10					
15	4/1		e(P)	07-31-26				610km.	Somaliland.
			i	-34					
			iS	32-32					
16	4/1		e(P)	07-42-20				590km.	Somaliland.
			S	43-23					
17	4/1		P	08-03-34				680km.	Somaliland.
			i	-42					
			S	04-46					
18	4/1		e(P)	08-22-51				590km.	Somaliland.
			S	23-54					
19	4/1		iP	09-31-23				680km.	Somaliland.
			S	32-24					
20	4/1		eP	11-33-31				605km.	Somaliland.
			S	34-36					
21	4/1		eP	11-36-57				540km.	Somaliland.
			i	37-06					
			S	-55					
			Mz	38-42					
22	4/1		i(P)	11-48-06					
			i	49-055					
23	4/1		i	11-53-27					
24	4/1		eP	12-12-35				595km.	Somaliland.
			S	13-38					
25	4/1	12-51-52	iP	12-59-11	45N	27E			Rumania.
26	4/1		e	14-27-33					
			i	28-38					
27	4/1		iP	15-43-50					
			(S)	44-48					
28	4/1		eP	16-43-02					
			(S)	44-04					
29	4/1		eP	17-50-37				600km.	Somaliland.
			iS	51-41					
30	4/1		iP	21-15-24				640km.	Somaliland.
			S	16-32					
31	4/1	22-07-00*	eP	22-08-12					Somaliland.
				09-26					
32	5/1		P	00-59-39				580km.	Somaliland.
			S	01-00-41					
33	5/1		e	02-50-25					
34	5/1		e	03-25-22					
35	5/1	06-07-33*	iP	06-14-39	46N	26.9E	160km.		Rumania.
36	5/1		iP	19-48-27				580km.	Somaliland.
			S	49-30					
37	6/1		e	01-41-20					
			e	42-22					
38	6/1		eP	02-51-42				580km.	Somaliland.
			iS	52-45					
39	6/1		eP	17-45-17				575km.	Somaliland.
			iS	46-18					
40	6/1	22-56-52*	iP	23-02-105	32N	54½E			S. Iran.

No.	DATE	ORIGIN TIME U.T.	PHASES		Lat.	Long.	h (km)	d° (km)	Location & Remarks
41	7/1		iP	05-11-08				600km.	Somaliland.
			S	12-12					
42	7/1	08-15-21	P	08-25-06	6½N	94E			Nicobar Is.
43	8/1		e	07-38-12					
			i	39-36					
44	8/1	07-44-08*	PKP	08-03-58	17S	172½W			Samoa Is.
45	8/1	11-29-18	iP	11-41-58	55S	27½W			Sandwich Is.
46	8/1		(P)	11-48-35				570km.	Somaliland.
			iS	49-36					
47	8/1	14-45-53	iP	14-58-33	55½S	27½W			Sandwich Is.
48	8/1		P	15-11-27				590km.	Somaliland.
			S	12-30					
49	8/1		iP	17-44-46				215km.	
			S	45-11					
50	9/1	03-58-45	P	04-05-(02)	37N	29E			S.W. Turkey
51	9/1	07-23-50	iP	07-31-16	36N	69E	150-200km.		Hindu Kush
			S	37-08					
			ScS	41-02					
52	9/1		i	18-21-03					
53	9/1		e	23-09-(31)					Central Africa
54	10/1		P	22-44-46				570km.	Somaliland.
			S	45-47					
55	11/1	02-27-38	eP	02-40-33	28½N	131E			Ryukyu Is.
56	11/1	03-10-14	e	03-20-00	16N	96½E			S. Burma
57	11/1		i	16-06-49					
			i	07-51					
58	11/1		i	16-55-27					
59	11/1		i	18-30-44					
			i	31-48					
60	12/1	03-09-10	eP	03-21-49	55½S	27W			Sandwich Is.
61	12/1		i	14-11-36					
62	12/1		i	14-23-41					
63	12/1	22-22-37*	ePKP	22-42-26	16S	173½W			Samoa Is.
64	13/1		iP	01-56-00				610km.	Somaliland.
			iS	57-05					
65	13/1		i	08-09-45					
66	13/1		i	12-50-31					
67	13/1		i	13-11-02					
68	13/1	15-40-34	eP	15-55-(19)	16S	72W	200km.		S. Peru
			PP	59-50					
			PPP	16-02-24					
			PS	09-38					
			SS	16-04					
69	14/1	10-25-52	iP	10-39-08	37N	140E	80km.		Hondo, Japan.
70	14/1		eP	14-42-40					S. Atlantic (?)
71	14/1	21-25-15	iP	21-37-36	11N	43W			Atlantic Ocean.
72	15/1	09-30-24	iPKP	09-48-59	15S	75W	150km.		coast of Peru.
			PP	50-04					
			S	59-52					
73	15/1		iP	17-11-48				560km.	
			S	12-48					
74	16/1		iP	06-39-42				560km.	
			iS	40-42					
75	16/1	12-30-56	iP'	12-49-29	20½S	178W	600km.		Fiji Is.
76	16/1	20-49-31	iPKP	21-08-09	63N	151W	150km.		Alaska
77	18/1	09-04-43	eP	09-17-(35)	5N	126½E			S. of Mindanao, P.I.
78	19/1		i(P)	09-12-30					
			iS	13-25					
79	19/1	09-15-04	iPKP	09-33-38	23S	180E	600km.		S. Fiji Is.
80	20/1		i	15-01-30					
			i	02-25					
81	20/1		i	17-37-(14)					
			i	38-09					
82	21/1	10-43-33	ePKP	11-02-26	16S	179½E	600km.		Fiji Is.
83	21/1		iPg	12-58-34				545km.	
			iS	59-38					
84	22/1		iP	00-04-33					
			(S)	05-03					
85	22/1	13-35-54	eP	13-48-44	0	125E			Molluca Passage.
86	23/1		i	01-19-46					
87	23/1	04-40-56	eP	04-54-01	4S	127½E			Ceram Is.
			S	05-05-14					
88	23/1	06-24-08	iPKP	06-43-06	17S	177W	400km.		Fiji Is.
89	23/1	07-31-14	eP	07-44-18	4S	127½E			Ceram Is.
				54-59					
			S	55-21					
90	23/1	17-56-30	eP	18-09-34	4S	127½E			Ceram Is.
			S	20-(08)					

No.	DATE	ORIGIN TIME U.T.	PHASES		EPICENTER Lat.	Long.	h (km)	d° (km)	Location & Remarks
91	24/1	04-21-42	ePKP	04-41-(28)	15½S	179W			Fiji Is.
92	25/1	16-29-26	ePKP	16-49-34	16S	179W			Fiji Is.
93	25/1		e	20-12-50					
94	25/1		i	20-25-03					
			i	26-09					
95	25/1	21-34-04*	eP	21-39-43	27½N	51E			Persian Gulf.
96	26/1		e	01-14-47					
			i(Pg)	14-57					
			(Sg)	15-58					
97	26/1	01-48-36*	iP	01-54-01	28½N	56E			south of Iran.
98	26/1		e	02-11-41					
			e	13-14					
99	26/1	03-17-03	iP	03-27-07	16½S	14½W			S. Atlantic.
100	26/1	09-52-00	iP	09-58-31	39½N	39½E			Turkey.
101	26/1	13-05-40	iP	13-11-43	38N	29E			Turkey.
102	26/1	13-13-12*	iP	13-19-13	36¾N	24¾E			S. Turkey.
103	26/1	20-27-05	iP	20-34-11	46N	26½E	150km.		Vrancea, Rumania.
104	29/1	07-33-43	iP	07-41-02	36½N	70½E	200km.		Hindu Kush.
105	29/1	07-46-17	iP	07-57-23	·58S	10E			Bouvet Is.
106	29/1		Pg	14-13-47				570km.	
			Sg	14-53					
107	29/1		iPg	19-00-17				520km.	
			iSg	01-18					
108	29/1		e	22-53-07					
			i	54-29					
109	30/1	10-52-45*	iPKP	11-12-25	20¾S	175½W			Tonga Is.
110	30/1		e	17-41-41					
			i	43-03					
111	31/1	05-08-18	eP	05-21-20	33½N	134½E			E. Shikoku, Japan.
112	31/1	19-07-23	ePKP	19-27-23	16S	172¾W			Samoa Is.
113	1/2	11-59-34	iP	12-05-51	35N	23½E			W. Crete.
114	2/2		iP	01-55-40					
			S	56-29					
115	2-3/2	23-51-57	eP	24-02-39	34½N	104½E			Kansu Prov., China.
116	3/2	02-20-55	ePKP	02-40-19	37S	179E			North Island, N.Z.
117	3/2	14-28-39	iPKP	14-48-31	19S	173½W			Tonga Is.
118	4/2	03-46-30	eP	04-01-43	4½S	153½E	100km.		New Ireland.
119	4/2	07-07-20	iP	07-12-42	29N	52E			S. Iran.
120	4/2	10-20-39	iP	10-28-46	35½N	78E	100km.		Kasmir.
121	4/2	16-50-30	eP	17-03-55	39N	143E			E. Japan.
			S	14-39					
122	4/2	20-38-20	iPKP	20-56-55	18½S	179W	600km.		Fiji Is.
123	6/2	17-10-45	eP	17-21-46	6S	104E			Sumatra.
124	7/2	10-07-50	iP	10-19-24	5N	123E	600km.		Celebes Sea.
125	7/2	11-16-54	$ePKP_1$	11-36-43	15½S	173½W			Samoa Is.
			$iPKP_2$	-48					
126	8/2	12-45-34	ePP	13-03-28	58S	67W			Drake Strait.
127	8/2	18-54-23	eP	19-03-27	36½N	70½E	150km.		Hindu Kush.
			PP	04-11					
128	9/2	11-56-12	eP	12-09-17	4S	128E			Banda Sea.
129	10/2	23-55-49	eP	00-08-50	4S	128E			Ceram Is.
			S	19-54					
130	10/2	01-59-05	eP	02-13-14	3½S	128E			Ceram Is.
131	10/2		i	15-09-03					
132	10/2	23-19-55	$ePKP_1$	23-39-47	15½S	173W			Samoa Is.
			$iPKP_2$	40-03					
133	11/2		eP	10-21-56				535km.	
			S	22-59					
134	11/2	20-56-08	iPKP	21-15-21	11½S	166½E			Santa Cruz Is.
135	12/2		i	11-52-37					
			i	53-31					
136	12/2		iP*	19-38-13				210km.	Most probably from the
			iPg	38-19					region of Kara Kore,
			iSg	38-44					N 10.5, E 39.5
137	12/2		P*	19-41-58				200km.	same
			Pg	(on T.M.)					
			Sg	42-34					
138	12/2		eP*	19-51-53				210km.	same
			Pg	-59					
			Sg	52-25					
139	12/2		iP*	19-56-53				210km.	same
			iPg	-59					
			iSg	57-23					
140	12/2		iPg	19-58-46				215km.	same
			iSg	59-13					
141	12/2		(Pg)	20-06-23				210km.	same
			(Sg)	-48					

No.	DATE	ORIGIN TIME U.T.	PHASES		EPICENTER Lat.	Long.	h (km)	d° (km)	Location & Remarks
142	12/2		P*	20-54-32					
			iPg	-38					
			Sg	55-(03)					
143	12/2		iP*	21-06-22					
			Pg	-28					
			Sg	-53					
			M	07-01					
144	12/2		iP*	21-11-53					
			iPg	-59					
			Sg	12-23					
			M	-29					
145	12/2		Pg	21-13-26					
			Sg	-51					
146	12/2		iPg	22-00-27					
			iSg	-53					
147	12/2	23-17-30*	ePKP	23-37-22	15½S	173W			Samoa Is.
148	13/2		P*	07-41-23					
			Pg	-29					
			Sg	-54					
149	13/2		Pg	07-45-23					
			Sg	-49					
150	13/2		iPg	15-42-42					
			Sg	43-07					
151	13/2	15-41-04	iP	15-54-04	1½N	127½E			Halmahera.
			eS	16-04-24					
152	13/2	20-40-06	ePKP	20-58-41	17½S	70W	150km.		Peru.
153	13/2		iP	23-52-09				245km.	
			S	-37					
			Mz	-43					
154	14/2		e	04-30-(19)					
155	14/2		e	10-59-36					
			i	11-00-41					
156	14/2	12-51-15	eP	13-00-50	12½N	92½E			Andaman Is.
			iPcP	01-40					
157	14/2	19-28-59	iP	19-36-24	25S	69½E			Indian Ocean.
158	16/2		P*	01-27-59					
			Pg	28-05					
			Sg	-30					
159	16/2	13-14-31	(P)	13-27-03	22N	45½W			Atlantic Ocean.
160	16/2		iP*	17-43-56				200km.	
			iP	-59					
			iS	44-23					
161	16/2		i	17-58-24					
162	16/2		iP	18-05-00					
163	16/2		i	19-50-55				100km.	
			i	51-08					
164	17/2	00-01-28	ePKP	00-21-08	20½S	175W			Tonga Is.
165	17/2		e(P)	11-48-21					
			i(S)	51-03					(two different events?)
166	17/2	12-32-10	iPKP	12-51-57	30S	112½W			Easter Is.
167	18/2		eP	10-01-(23)					
			(S)	02-50					
168	19/2	10-36-46	iP	10-44-13	36N	70½E	200km.		Hindu Kush.
169	20/2		iP	01-45-03					
			iz	-17					
			(S)	-33					
			Mz	46-53					
170	20/2	06-05-28	ePKP	06-24-37	17½S	177½W	200km.		Fiji Is.
171	20/2	14-40-08*	iP	14-46-34	37½N	44½E			E. Turkey.
172	20/2		e	19-54-10					
			e	55-23					
173	21/2	00-46-56	ePKP	01-05-53	42S	173E	60km.		South Island, N.Z.
174	21/2	08-13-31	eP	08-21-25	36N	4½E			Algeria.
175	21/2		iz	08-36-05					
176	21/2	09-29-15	iP	09-35-26	38N	42E			Turkey.
177	21/2	09-39-36	ePKP	09-57-56	20S	178½W	600km.		Fiji Is.
178	22/2	00-54-30	iPKP	01-13-01	20S	178½W	600km.		Fiji Is.
179	22/2	21-04-09	i	21-11-05	39N	21E			Greece.
180	23/2	00-30-52	iP	00-37-48	39N	20½E			Greece.
181	23/2	02-09-42	iP	02-17-10	36N	70E			Hindu Kush.
182	23/2		e	04-38-16					
			i	-22					
			M	39-33					
183	23/2	07-34-30	iP	07-41-19	39N	20E			Greece.
184	23/2	07-47-51	iP	07-54-39	39N	20½E			Greece.
185	23/2	11-31-04	iPKP	11-49-46	19S	178W	500km.		Fiji Is.
186	23/2	16-04-50	iP	16-16-33	6S	154½E			Solomon Is.

No.	DATE	ORIGIN TIME U.T.	PHASES		EPICENTER Lat.	Long.	h (km)	d* (km)	Location & Remarks
187	23/2		e	22-56-53					
			i	-59					
			e	57-07					
188	23/2		iP	23-28-14					
			i	-33					
189	23/2		e(P*)	23-56-37					
			i(Pg)	-43					
			i(Sg)	57-07					
190	24/2	18-55-20	eP	19-01-32	38N	41E			Turkey.
191	24/2	21-37-04	iPKP	21-55-57	7½S	156E			Solomon Is.
192	25/2		iP	20-47-09				175km.	
			(Sn)	-25					
			S,	-29					
193	26/2	01-06-23	eP	01-19-53	2½S	128E			Ceram Sea.
194	26/2	06-32-36	iPKP	06-52-24	20S	174W			Tonga Is.
195	27/2	08-56-00	i	09-16-13	30½S	179½W			Kermadec Is.
196	27/2	23-05-49	iP	23-18-24	2N	123E			Celebes Sea.
197	28/2		e	10-26-08					
			i	-19					
198	29/2	05-22-53	eP	05-35-01	14N	120E	150km.		S.W. Luzon Is.
199	29/2	23-40-14*	iP	23-49-13	30°27'N	9°37'W			Agadir, Morocco.
			i	-17					
			S	56-29					
			"	-31					
			R	24-08					
200	1/3	19-53-33	iPKP	20-19-17	22S	175W			Tonga Is.
201	2/3		i	04-38-09					
			i	39-22					
202	2/3	12-18-05*	iP	12-23-33	32N	50¼E			Iran.
203	2/3	21-56-25	eP	22-07-49	52N	30W			Atlantic Ocean.
204	3/3		i	11-45-13					
				-23					
205	4/3		iPg	00-18-08				190km.	
			Sg	-31					
206	4/3	03-53-00	iP	04-05-435	31N	129E	100km.		S. Japan.
207	4/3	16-25-25	eP	16-36-27	72N	1½W			Jan Mayen Is.
208	4/3	21-05-45	iP	21-15-26	7½N	94E			Nicobar Is.
209	5/3	11-25-00	e	11-39-22	29N	81E			Nepal.

NOTE:

Technical trouble with the suspension of the Willmore vertical seismometer was the cause of a lower level of sensitivity, and, on certain days, of a complete loss of record. This accounts for the reduced number of earthquakes recorded during the following period.

No.	DATE	ORIGIN TIME U.T.	PHASES		EPICENTER Lat.	Long.	h (km)	d* (km)	Location & Remarks
210	8/3	16-33-38	iPKP	16-52-26	16½S	168½E	250km.		New Hebrides.
211	11/3		Pg	23-58-01				230km.	
			Sg	-28					
			i	-33					
212	12/3		e	02-53-21					
213	12/3	11-54-00	iP	12-01-10	42N	21E			Macedonia.
214	12/3		iP	23-05-16					
				06-20					
215	12/3		i	23-13-09					
			i	-14					
			i	-20					
			i	-25					
216	13/3		iPg	20-28-31				110km.	
			Sg	-44					
			M	-48					
217	13/3		iPg	20-31-08				125km.	
			Sg	-23					
			M	-27					
218	13/3		iPg	20-32-26				110km.	
			iSg	-39					
			M	-41					
219	14/3		eP	01-43-13					
			i	44-42					
220	14/3		Pg	05-12-11				240km.	
			Sg	-41					
221	14/3		ePg	13-13-13				235km.	
			Sg	-42					
222	14/3	20-14-33	iP	20-19-59	29N	49½E			Persian Gulf.
223	15/3	10-08-58	ePKP	10-28-48	20S	174W			Tonga Is.
224	16/3	17-39-16	ePKP	17-59-10	15½S	173½W			Samoa Is.

No.	DATE	ORIGIN TIME U.T.	PHASES		EPICENTER Lat.	Long.	h (km)	d* (km)	Location & Remarks
225	16/3		e	23-35-09					
226	18/3		e	02-40-50					
			i	41-57					
227	18/3		e	03-25-47					
			i	27-00					
			i	28-24					
228	25/3	09-45-44*	iP	09-47-42	12N	46¾E			(possibly a second event.)
			(S)	48-48					Gulf of Aden.
			L	49-43					
			M_{ns}	51-22					
229	27/3		iP	08-50-16					
			(S)	-52					
230	29/3	06-30-54	PKP	06-50-18	17S	167E			New Hebrides.
231	4/4		e	10-05-12					
232	4/4		e	12-32-11					
233	5/4	07-17-45	eP	07-30-29	61S	26W			Sandwich Is.
234	5/4	12-36-15	eP	12-49-01	60½S	25W			Sandwich Is.
235	7/4	23-55-54	ePKP	24-15-12	21S	177W	200km.		Tonga Is.
236	9/4		iPg	23-13-43					
			(S)	14-42					
237	11/4		iP	20-54-48					
			(S)	55-04					
238	13/4		e	08-20-26					
			i	21-32					
239	13/4		iP	23-57-41					
240	15/4	03-25-38	ePKP	03-45-34	27S	113W			Easter Is.
241	16/4		e	09-09-43					
242	20/4	19-23-04	eP	19-30-29	37N	71E	200km.		Hindu Kush.
243	20/4	21-02-48	eP	21-08-12	27½N	54½E			Teheran, S. Iran.
244	21/4	02-16-29	ePKP	02-36-22	2½S	110W			c.2000km. W. of Galapagos Is
245	21/4		iPg	03-29-15				185km.	
			Sg	-37					
246	22/4	20-26-28	ePKP	20-45-51	17½S	174½W	200km.		Tonga Is.
			i	-55					
247	23/4	06-26-16	eP	06-31-40	31½N	50½E			Iran.
248	24/4	03-22-23	iP	03-33-19	6S	113½E	600km.		Java Sea,
			S	42-17					
249	24/4	12-14-26	iP	12-19-45	28N	54½E			Lar, S. Iran.
			iS	24-11					
			L	27-41					
250	25/4	16-28-32	iP	16-35-07	38½N	25E			Aegean Sea.
251	29/4	19-32-12	eP	19-44-44	0	122E			Celebes
			S	55-05					
252	29/4	04-01-32	S	04-24-22	0	122E			Celebes.
253	6/5		iPg	16-47-36				200km.	
			Sg	48-00					
254	6/5		P*	21-30-07				470km.	
			Pg	-18					
			Sg	31-13					
			Mz	-19					
255	8/5		eP	13-15-12					
			(S)	16-24					
256	9/5	00-11-10	eP	00-23-54	30½N	129½E			Ryukyu Is.
257	10/5	21-51-55	i	21-57-59	27N	47½E			N.E. Saudi Arabia.
258	11/5		e	18-49-37					
259	13/5		iP	16-26-54					Alaska ?
260	18/5	06-35-09	e	06-47-50	29N	130E	100km.		Ryukyu Is.
			iP	-53					
261	18/5	08-40-57	iP	08-46-08	27N	52½E			Persian Gulf.
			S	50-25					
262	18/5		e	14-24-06					
263	19/5	02-07-00	eiP	02-14-24	36N	71E	200km.		Hindu Kush.
264	19/5	10-11-51	iP	10-19-16	17S	66E			Mascarene Is.
			S	25-26					
			L	28-10					
265	19/5		e	16-24-28					
			i	25-27					
266	19/5		iPg	23-23-37				155km.	
			iSg	-56					
267	20/5	04-14-18	eP	04-19-28					Persian Gulf.
			S	23-42					
268	20/5	11-12-31	ePKP	11-31-47	28S	167½E			Norfolk Is.
269	21/5	06-41-10	iP	06-47-56	37½N	21E			W. of Greece.
270	21/5	10-02-50	eP	10-18-06	37½S	73½W			coast of Chile.
			PKP	22-02					
			PP	23-07					
			SS	32-18					
			SSS	43-42					

No.	DATE	ORIGIN TIME U.T.	PHASES		EPICENTER Lat.	Long.	h (km)	d* (km)	Location & Remarks
271	22/5	18-55-57	eP	19-11-05	38S	73½W			Chile.
			PP	15-28					
			SSS	30-26					
272	23/5	05-13-35	e	05-32-03	38S	73½W			Chile.
273	23/5	09-52-20	e	10-11-45					Chile.
274	24/5	14-46-34	ePKP	15-05-47	44½S	167½E			South Island, N.Z.
275	25/5	08-34-33	e(PKP)	08-53-30	45S	76W			coast of Chile.
276	25/5		iP	12-55-14					
			(S)	59-33					
277	26/5	05-10-05	iP	05-17-12	40N	20E			Albania-Greece.
			S	22-53					
			L	30-40					
278	26/5		i	13-53-11					
279	26/5		i(Pg)	18-03-30					
			i(Sg)	-47					
280	26/5	20-05-07	eP	20-14-35	27N	93E			E. India.
281	27/5		ei	01-12-59					
282	28/5		e	19-47-23					
283	28/5		eP	19-51-34					
284	29/5	07-39-29	e	07-58-57	38S	72½W			Chile.
285	29/5		ePg	19-09-37				290km.	
			Sg	10-11					
286	29/5		e	21-32-09					
287	29/5		e	23-38-30					
288	29/5		ePg	23-54-00				155km.	
			iSg	-19					
289	30/5		e	11-21-42					
			L	26-12					
290	31/5		eP	00-27-46					
			i	30-50					
			(S)	31-16					
291	31/5	11-02-20	ePP	11-19-49	18N	62W			Leeward Is.
292	31/5	21-00-40	eP	21-11-15	5½S	109½E	600km.		Java Sea.
293	1/6		iP	00-34-22				580km.	
			(S)	35-22					
294	1/6		e(P)	17-10-59					local.
			(S)	11-27					
295	2/6		i	02-04-33					
296	2/6	07-19-10	iPKP	07-38-40	19S	175W	150km.		Tonga Is.
297	2/6	07-22-30	eP	07-28-54	33½N	60E			Iran.
298	2/6	18-59-05	ePKP	19-17-41	20½S	178½W	550km.		Fiji Is.
			PP	20-31					
299	3/6	13-14-38	ePKP	13-33-07	17½S	179½W	600km.		Fiji Is.
300	3/6	13-23-37	ePKP	13-42-07	17½S	179W	600km.		Fiji Is.
			ePP	44-52					
301	4/6		e	03-25-40					
302	4/6		e	08-20-54					
303	5/6		e(Pg)	04-51-13					local.
			(Sg)	-28					
304	5/6		e	01-37-09					
305	6/6		eP	22-48-48					local.
306	7/6	15-34-50	iP	15-39-13	14N	57E			Arabian Sea.
307	7/6		e	22-15-03					
308	8/6		iPg	02-12-09				110km.	
			Sg	-22					
309	8/6		iPg	03-54-00					local.
310	8/6	16-19-48	iP	16-31-14	35N	35W			N. Atlantic Ocean.
311	9/6		e	11-43-14					
312	9/6		eP	17-58-26					
313	10/6		iPg	17-24-34				195km.	
			Sg	-57					
314	10/6	21-12-05	ePKP	21-31-56	15½S	174W			Samoa region.
315	12/6		e	18-07-02					
316	15/6	15-36-51	eP	15-50-14	41N	142½E			N. of Honshu, Japan.
317	15/6		e	23-41-06					
318	15/6	23-32-35	ePKP	23-50-59	26S	178½E	600km.		S. Fiji.
319	16/6	10-20-04	iP	10-26-36	2S	69E			Indian Ocean.
320	17/6		iP	10-50-25				700-800km.	
			i(Pg)	-48					
			S_{ns}	51-38					
			S_{ew}	-40					
321	17/6		iP	16-56-28				620km.	
			(S)	57-34					
322	17/6		eP	18-40-35				560km.	
			(S)	41-21					
323	17/6		e	23-14-47					

No.	DATE	ORIGIN TIME U.T.	PHASES		EPICENTER Lat.	Long.	h (km)	d* (km)	Location & Remarks
324	19/6		iP	20-22-11				700-800km ?	
			Pg	-36					
			S_{ns}	23-24					
			S_z	-25					
			S_{ew}	-26					
325	20/6	02-01-08	PP	02-20-48	38S	73½W			coast of Chile.
326	20/6	12-59-40	ePP	13-19-08	39½S	73W			Chile.
327	21/6	21-33-45	iP	21-46-22	61S	21W			Sandwich Is.
328	22/6	16-12-00	eP	16-16-27	12N	57½E			Arabian Sea.
			iP	-28					
329	25/6	14-41-42	ePKP	15-01-(23)	30½S	177W			Kermadec Is.
330	25/6		eP	18-23-14				450km.	
			S	24-09					
331	28/6		i	12-16-48					
332	28/6		eP	21-17-03					local.
			i(S)	18-09					
333	29/6		i	04-48-49					
334	29/6		eP	14-08-(40)					local.
			(S)	09-41					
335	30/6		e	23-30-(48)					local.
			i	31-16					
336	30/6		e	23-40-29					local.
			i	41-41					

METEOROLOGICAL DATA

JANUARY - JUNE 1960

Location of the Observatory

Geographic coordinates	:	North 09° 01' 45" East 38° 45' 56"
Elevation	:	2442.5 meters

Data

TEMPERATURE	:	-The maximum and minimum values are from Fuess thermometers. -The mean value is obtained by integration of a Fuess thermograph record corrected every day for base-line and scale variations.
PRESSURE	:	-The mean value is obtained by integration of a Negretti & Zambra microbarograph record R31241 controlled with a Negretti & Zambra mercury barometer, Kew type, M9253.
HUMIDITY	:	-The mean R.H. % value is obtained by integration of a Fuess meteorograph record. Control af the base-line and sensitivity is made with an Assmann psychrometer A9204.
WIND	:	-Maximum and mean values are from a Fuess recording anemometer. -The mean direction vector is given by an eight-point direction pulse-recorder and is calculated from 0° to 360°, clockwise, from North.
RADIATION	:	-Solar radiation values in cal. cm^{-2} are from a Fuess radiation meter, Robitzch type, model 58c, giving the total direct solar and diffuse celestial radiation reduced to a horizontal plane. -The hours of sunshine are from a Campbell - Stokes recorder.
PRECIPITATION	:	-The rain gauge is a Bendix - Friez Universal recorder, model 775-B, with an 8" collector.
EVAPORATION	:	-The instrument is a Piche Evaporimeter. The data recorded in cc are multiplied by the factor 0.68 to give the depth of evaporation in millimeters, as from a free surface.

METEOROLOGICAL DATA

M 1 — JANUARY 1960

DATE	TEMPERATURE °C Max	Min	Mean	Pa mb Mean	R.H. % Mean	WIND m/sec. Max	Mean	θ°	SUNSHINE Cal/cm 2	Hrs	RAIN mm	EVAPORATION mm
1	20.5	9.7	14.3	766.9	66	4.6	1.63	103	314	2.1		3.05
2	20.9	6.8	14.2	767.6	63	5.3	2.06		358	8.2		4.95
3	21.0	7.2	13.7	768.2	58	4.7	1.42	98	507	8.3		4.95
4	22.0	4.7	12.8	767.4	58	5.3	1.86	121	570	10.3		5.01
5	21.5	5.3	13.1	765.9	57	4.9	1.88	137	468	6.3		5.47
6	23.0	5.7	14.5	765.2	51	4.2	2.08	107	558	10.2		6.5*
7	23.7	6.5	15.6	765.5	45	7.5	2.76	133	569	10.7		8.98
8	22.1	10.6	15.9	763.3	48	7.4	2.68	106	564	10.8		7.60
9	22.0	7.4	14.4	768.5	68	5.9	2.10	66	454	8.0	2.0	4.72
10	21.5	8.5	15.6	768.5	59	4.7	2.05	51	430	7.4		5.24
11	21.4	6.8	14.6	768.0	56	5.6	2.11	144	466	8.0		6.05
12	21.7	6.0	14.4	768.2		4.9	1.99	155	446	7.5		5.87
13	20.5	9.0	15.1	767.7	52	4.8	1.98	66	347	5.4		5.38
14	22.5	6.7	14.4	767.4	51	5.4	1.97	121	544	9.5		5.90
15	18.5	5.8	12.4	768.2	60	5.9	2.10	96	411	6.2		3.97
16	20.4	4.0	11.6	767.5	51	5.9	2.37	88	590	9.7		8.47
17	21.3	-1.2	9.5	766.8	30	9.1	1.96	53	592	10.9		9.88
18	20.5	-1.8	9.5	767.6	22	6.5	2.39	106	610	11.0	6.8	8.98
19	18.5	-1.2	8.9	768.0	27	6.0	2.16	98	604	11.0	12.6	7.95
20	18.8	-0.4	9.6	766.8	32	4.9	2.03	104	553	10.5		7.60
21	18.7	0.5	9.1	766.4	38	4.8	1.86	108	495	4.7		5.76
22	21.4	1.5	11.2	766.4	41	4.8	2.03	100	536	9.8		7.43
23	22.0	3.5	12.8	767.3	40	5.2	1.79	129	573	10.1		7.08
24	21.4	6.2		767.7		5.9	2.01	142	469	8.6		6.28
25	21.0	6.6		767.7		6.2	2.62	121	518	10.3		6.91
26	21.4	5.5	14.5	768.6	42	7.2	2.71	105	574	10.3		9.22
27	21.1	4.1	13.3	768.4	33	5.9	2.41	109	593	10.8		9.33
28	23.1	3.2	13.7	768.2	33	4.9	1.98	112	579	10.5		7.72
29	22.8	5.2	14.3	767.8	42	4.7	2.03	146	546	10.1		6.62
30	20.6	9.3	14.5	767.2	62	5.4	2.45	132	461	5.5	3.0	5.01
31	15.2	11.3	11.9	767.4	81	5.3	2.22	121	162	0.2		2.88
SUM											24.4	
Mean	21.0	5.2	13.1	767.3	49	5.6	2.12	110	499	8.5		6.47

METEOROLOGICAL DATA

M 2 — FEBRUARY 1960

DATE	TEMPERATURE °C Max.	Min.	Mean	Pa mb Mean	R.H. % Mean	WIND m/sec Max.	Mean	θ°	SUNSHINE Cal/cm 2	Hrs	RAIN mm	EVAPORATION mm
1	16.5	9.7	13.0	768.1	78	4.8	1.62	137	270	1.1		2.82
2	19.0	8.5	12.7	768.5	77	5.9	1.76	118	361	3.6	1.0	2.71
3	22.3	6.8	13.8	767.5	61	5.5	1.62	104	469	6.6	1.0	4.72
4	23.2	6.6	15.8	767.2	38	7.6	2.83	123	625	8.8	1.3	11.06
5	23.4	5.9	15.5	767.3	33	6.6	2.97	136	632	10.5	1.2	11.23
6	21.5	7.6	18.5	767.2	44	8.5	2.74	133	576	10.6		7.49
7	21.8	5.9	14.2	766.7	46	7.1	2.57	112	621	10.2		9.38
8	22.7	6.5	15.0	766.2	30	6.9	2.54	105	613	10.7		10.54
9	24.1	7.0	16.8	766.1	28	5.6	2.06	108	631	10.6		9.85
10	24.5	6.4	16.4	765.6	27	5.5	2.04	104	616	10.7		10.77
11	23.7	6.8	16.4	765.2	32	7.1	2.35	133	629	10.6		9.96
12	24.0	8.9	16.2	766.5	38	5.9	2.03	72	579	10.0		8.06
13	23.5	8.0	15.2	767.0	54	6.0	2.16	76	478	6.7		5.24
14	23.6	8.2	15.3	767.2	52	6.2	1.99	72	508	8.2		5.36
15	22.7	8.1	15.6	766.5	52	6.8	2.72	96	532	10.2		7.54
16	21.3	7.2	15.7	767.3	50	7.8	2.39	93	552	11.0		7.14
17	23.0	6.1	15.2	767.1	48	6.8	2.05	85	564	10.1		6.74
18	23.7	11.2	16.6	768.4	50	5.6	2.10	79	560	8.9		7.60
19	22.5	6.7	15.4	764.8	47	7.1	2.75	97	534	9.7		8.93
20	22.8	7.0	15.9	765.8	37	7.6	3.08	116	572	10.8		10.77
21	23.7	9.4	17.2	767.5	30	5.8	2.10	110	541	7.2		10.43
22	23.7	10.9	17.8	766.9	28	5.9	2.51	121	582	9.8		11.00
23	23.0	6.9	16.3	767.2	31	6.5	2.41	100	633	11.0		11.23
24	23.5	6.9	15.9	767.1	33	7.1	2.09	80	600	9.8		9.62
25	24.5	7.7	16.3	766.3	36	5.6	1.97	106	565	8.7		10.66
26	24.2	7.8	16.9	766.0	38	5.8	2.14	133	582	10.2		10.66
27	24.5	8.6	17.3	766.4	33	6.0	2.06	101	621	9.6		10.66
28	24.5	7.0	16.5	765.7	33	5.3	2.42	54	631	11.3		11.25
29	24.4	7.1	16.2	764.9	33	7.2	2.52		629	11.2		12.44
SUM											4.5	
Mean	23.0	7.6	15.9	766.7	42	6.4	2.30	104	562	9.3		8.83

METEOROLOGICAL DATA

M 3 MARCH 1960

DATE	TEMPERATURE °C Max.	Min.	Mean	Pa mb Mean	R.H. % Mean	WIND m/sec Max.	Mean	θ°	SUNSHINE Cal/cm²	Hrs	RAIN mm	EVAPORATION mm
1	25.0	7.5	17.2	765.1	28	6.8	2.35	117	650	10.4		12.55
2	25.0	6;9	17.2	765.5	33	6.0	2.12	157	585	10.1		10.14
3	24.1	8.5	17.4	766.4	42	5.6	2.05	124	533	9.9		6.97
4	22.0	9.4	15.3	766.8	66	6.3	2.46	109	347	2.5	1.0	5.01
5	23.0	10.0*	16.0*	767.5	58	7.3	2.87		581	9.6		9.04
6	20.6	6.6	14.3	765.6	52	7.8	2.70	97	573	8.8		8.47
7	24.5	8.6	16.5	764.1	49	9.2	2.56	89	541	7.4		8.47
8	23.1	8.4	15.1	763.7	63	6.8	2.16	72	400	6.3	4.5	5.53
9	21.7	10.1	15.2	763.2	68	5.6	2.06	77	359	5.1	2.0	4.55
10	23.7	11.5	15.6	764.8	73	6.1	2.01	88	438	6.5	30.0	3.46
11	21.2	8.0	15.0	764.9	61	6.4	1.96	142	490	5.9	1.6	5.01
12	18.3	9.9	13.8	766,4	71	2.6	1.05	149	248	0.4	2.5	2.13
13	22.0	11.9	14.6	766.4	66	6.8	1.85	100	465	4.8		3.63
14	22.8	9.1	15.7	765.4	63	4.0	1.58	140	515	7.9		4.14
15	22.0	7.6	14.9	765.1	61	4.2	1.62	127	466	6.2		4.14
16	23.0	8.0	14.9	765.0	64	4.1	1.83	133	503	7.1	2.8	4.03
17	21.4	8.6	15.6	764.6	58	5.1	1.80	185	533	7.6		4.44
18	21.3	8.7	15.8	764.0	67	6.0	1.84	156	555	6.5		4.09
19	21.0	10.5	15.6	763.9	70	4.4	1.77	149	387	3.6	0.5	3.02
20	20.8	10.5	15.0	765.0	70	4.8	1.74	162	404	2.0	1.1	3.09
21	21.4	10.9	15.0	766.7	67	6.0	1.72	163	396	2.9	1.5	3.23
22	23.8	9.3	16.2	766.5	60	6.4	2.25	88	561	7.6	2.0	6.22
23	20.8	9.5	16.0	766.6	70	8.3	2.31	123	425	3.4	0.4	3.92
24	25.7	8.7	16.3	766.1	72	6.0	2.19	68	404	5.3	16.0	4.20
25	20.3	8.9	13.6	766.0	73	6.8	1.97	96	399	4.6	11.0	3.34
26	20.9	10.5	15.0	767.5	67	3.2	1.59	129	545	5.4	26.0	3.51
27	19.0	9.2	13.9	767.5	68	4.2	1.51	95	557	5.0	1.0	3.46
28	20.2	10.2	15.3	766.5	71	4.8	1.94	130	505	4.1		3.28
29	21.8	8.4	16.1	766.4	65	5.4	2.26	143	518	7.7		5.41
30	21.8	13.0	15.9	766.9	69	5.7	1.96	152	308	4.1	4.7	3.11
31	19.7	11.5	14.8	767.0	78	5.4	1.74	119	374	5.5	3.9	2.65
Sum											112.5	
Mean	22.0	9.4	15.5	765.7	64	5.7	1.99	120	469	5.9		4.97

METEOROLOGICAL DATA

M 4 APRIL 1960

DATE	TEMPERATURE °C Max.	Min.	Mean	Pa mb Mean	R.H. % Mean	WIND m/sec Max.	Mean	θ°	SUNSHINE Cal/cm²	Hrs	RAIN mm	EVAPORATION mm
1	20.4	10.8	15.5	766.2	70	6.0	1.81	110	475	5.8	2.0	3.80
2	22.9	9.4	15.9	766.3	55	6.8	2.44	136	644	10.5		6.74
3	22.7	6.7	15.0	765.3	48	6.9	2.31	122	628	10.9		7.78
4	23.2	5.5	14.3	764.4	37	7.6	2.28	118	686	11.0		9.91
5	24.0	5.7	16.0	765.3	33	7.4	2.37	143	684	11.0		9.79
6	22.7	7.0	15.6	766.7	42	8.3	3.08	126	670	11.2		10.37
7	22.3	7.2	15.7	767.8	41	7.3	2.96	112	679	11.1		10.00
8	23.0	7.6	16.6	767.9	43	6.1	2.31	123	540	10.8		8.52
9	24.2	8.3	17.5	765.1	47	5.2	1.86	137	543	9.3		7.43
10	23.9	11.2	17.9	764.3	48	5.0	1.73	72	541	7.9		6.85
11	22.0	11.8	15.4	765.3	75	7.4	1.53	144	414	3.8	23.1	2.53
12	22.1	11.3	15.6	765.7	74	5.6	1.94	118	447	3.3		3.63
13	18.7	12.4	14.5	766.1	82	3.5	1.63	114	286	0.7	5.1	1.73
14	20.1	11.4	14.9	765.1	71	4.4	1.38	62	406	4.2		2.13
15	19.6	10.0	14.3	764.1	72	5.7	1.47	107	295	1.0		3.19
16	22.5	10.7	16.4	764.4	58	6.8	2.56	132	553	8.3		6.51
17	22.5	9.3	16.4	766.0	51	7.8	2.87	107	636	10.2		9.44
18	23.7	10.5	17.6	766.4	34	7.4	2.88	115	672	11.1		10.54
19	24.1	8.5	17.0	767.0	36	6.0	2.42	97	633	11.0		8.92
20	25.4	8.0	17.2	766.7	37	5.7	2.10	123	599	10.6		8.92
21	26.4	8.0	18.0	765.6	39	7.3	2.40	98	669	11.2		10.48
22	24.8	10.0	16.7	764.9	57	7.8	2.51	77	440	6.5	7.3	4.60
23	22.6	11.0	16.1	766.9	64	6.4	2.01	180	495	5.9	12.7	5.58
24	20.6	11.7	15.9	765.1	67	6.0	1.60	50	376	3.2		4.27
25	22.6	10.2	16.3	766.5	64	9.6	1.96	98	488	7.5	4.5	4.26
26	21.6	10.3	16.8	766.3	60	4.8	1.95	94	430	5.8	1.6	4.60
27	23.6	10.0	17.0	766.4	50	6.4	2.32	102	501	8.6		7.08
28	22.8	10.9	16.9	766.3	53	5.4	2.44	115	555	9.0		7.72
29	25.2	8.4	17.3	766.3	50	7.3	2.40	119	587	9.1		8.47
30	21.5	9.8	16.3	766.7	58	6.8	1.75	107	371	4.3	5.6	
Sum											61.9	
Mean	22.7	9.5	16.2	765.9	54	6.5	2.18	112	531	7.8		6.75

M E T E O R O L O G I C A L   D A T A

M 5 — M A Y 1960

DATE	TEMPERATURE °C Max.	Min.	Mean	Pa mb Mean	R.H. % Mean	WIND m/sec Max.	Mean	θ°	SUNSHINE Cal/cm²	Hrs	RAIN mm	EVAPORATION mm
1	23.5	9.9	16.9	766.9	53	6.4	2.27	124	490	9.1		3.82
2	23.7	8.2	16.9	766.2	48	7.8	2.47	116	116	11.1		8.38
3	21.0	9.1	15.8	765.8	63	5.1	1.59	101	374	2.5	1.0	4.55
4	21.1	11.5	15.8	765.7	73	9.2	1.76	148	445	5.6	19.8	3.17
5	24.0	10.0	15.4	764.9	69	5.4	1.67	185	454	7.6	0.2	4.78
6	19.0	12.2	15.3	765.4	76	5.4	1.74		347	3.5		3.51
7	22.3	9.1	15.5	765.1	69	7.8	1.51	110	525	7.7	1.0	3.86
8	22.4	11.3	15.6	765.9	72	5.5	2.24	131	438	4.3	3.5	3.86
9	22.0	11.3	16.2	765.8	60	6.0	2.01	114	555	7.9		8.98
10	22.9	9.8	17.5	766.0	53	5.6	2.14	125	555	8.5		7.20
11	22.0	10.0	15.4	766.3	68	5.3	1.49	131	523	4.0	4.8	3.28
12	20.4	10.2	16.1	766.2	72	4.4	1.15	137	380	3.4	4.0	3.17
13	22.9	10.2	15.9	766.3	64	5.1	1.80	77	575	8.3	0.3	4.84
14	23.3	11.9	16.8	767.1	62	5.3	1.82	121	481	6.0	0.2	5.87
15	22.7	12.4	17.3	767.6	54	7.8	2.24	136	550	9.5		6.80
16	24.0	9.2	16.8	766.7	53	6.0	2.12	136	619	11.0		7.31
17	23.5	10.6	17.0	766.0	58	6.8	2.01	97	415	4.9		5.59
18	21.6	10.8	15.2	766.0	72	4.8	1.84	50	389	5.0	5.2	3.80
19	20.2	10.3	13.9	766.8	79	6.8	1.97	91	354	3.3	2.3	2.07
20	20.4	11.3	14.9	766.8	80	3.9	1.42	204	214	1.6	1.0	1.90
21	19.5	11.4	15.0	766.1	82	4.6	1.38	134	306	0.6		1.90
22	20.4	11.1	15.2	765.6	75	3.9	1.06	158	451	2.7		2.71
23	17.6	11.9	14.9	766.3	74	5.1	1.68	107	318	2.0		2.07
24	21.2	11.8	15.2	767.5	70	4.8	1.58	73	345	4.1	1;0	2.94
25	22.9	9.7	15.9	766.8	71	6.0	2.06	71	455	6.3	1.6	4.20
26	20.4	12.9	15.8	766.6	64	6.35	1.74	90	341	4.5	4.2	2.65
27	19.6	7.8	13.7	767.0	77	6.8	1.66	64	422	5.3		2.53
28	21.5	9.1	14.2	768.0	74	3.7	1.85	77	429	5.6		3.11
29	22.9	6.7	14.4	767.9	71	7.8	1.99	72	515	6.7	5.6	3.92
30	21.1	7.6	13.7	768.9	55	6.4	1.85	81	399	6.0		3.63
31	20.6	7.8	13.5	768.0	70	7.8	1.83	62	510	6.2	1.8	3.34
Sum											57.5	
Mean	21.6	10.2	15.5	766.5	67	5.9	1.80	113	446	5.6		4.32

M E T E O R O L O G I C A L   D A T A

M 6 — JUNE 1960

DATE	TEMPERATURE °C Max.	Min.	Mean	Pa mb Mean	R.H. % Mean	WIND m/sec Max.	Mean	θ°	SUNSHINE Cal/cm²	Hrs	RAIN mm	EVAPORATION mm
1	22.7	8.8	15.4	768.1	60	6.0	2.01	110	535	7.7		5.41
2	24.2	8.0	15.7	768.9	59	7.3	1.98	126	503	7.6		7.95
3	23.5	9.8	16.8	768.9	39	10.2	3.7	87	653	11.0		10.54
4	25.3	8.6	17.5	766.5	40	8.5	2.39	104	488	7.9		9.85
5	23.8	8.9	17.7	766.0	46	6.0	2.21	141	536	8.2		8.18
6	24.7	8.8	17.6	766.9	42	9.3	2.41	93	483	7.5		9.56
7	22.1	9.2	15.6	767.3	59	6.4	1.87	100	425	4.1	1.2	4.55
8	24.0	9.0	16.5	767.0	54	7.3	2.14	97	510	6.7		7.14
9	20.5	9.5	15.4	767.8	60	6.0	1.82	93	406	2.2	3.8	4.38
10	24.5	7.8	16.6	768.2	53	7.3	2.18	114	618	9.3		7.66
11	24.5	7.6	16.1	768.2	57	4.8	1.82	127	568	6.9		5.18
12	23.5	9.5	15.1	766.9	66	5.4	1.99	20	435	5.6		4.26
13	19.4	7.8	13.4	767.4	73	4.6	1.73	34	373	1.7	1.3	2.36
14	20.7	9.0	14.7	768.5	70	4.8	1.56	113	413	5.9	1.9	3.00
15	21.0	10.4	15.0	768.9	66	6.0	1.87	130	530	5.0		3.80
16	19.9	8.4	14.3	767.7	71	4.5	1.70	183	390	4.2		2.88
17	22.1	8.2	13.7	766.4	73	8.4	1.77	57	425	3.7	2.1	2.71
18	21.0	8.5	13.4	766.4	80	9.1	1.92	113	342	2.0	2.2	2.47
19	20.5	8.5	14.7	766.3	70	6.0	2.08	150	476	4.1	0.6	2.76
20	18.9	10.1	13.6	767.2	72	8.3	2.08	52	318	1.2	2.4	2.42
21	21.2	6.9	11.9	766.9	66	7.8	1.66	70	448	5.2	17.3	3.00
22	19.4	9.0	14.2	767.2	68	4.6	1.76	57	427	5.1	8.8	3.11
23	19.8	8.1	13.6	766.3	70	9.2	1.70	81	387	4.9	9.3	2.19
24	18.0	9.6	13.6	765.3	76	6.0	1.59	84	375	1.3	12.4	1.27
25	20.0	7.6	12.4	764.5	76	4.1	2.13	74	453	3.6	7.6	2.59
26	22.1	8.3	14.8	765.2	70	4.8	1.59	59	515	5.8	0.3	3.34
27	20.6	8.6	14.1	765.9	69	5.6	1.57	354	440	2.9	6.6	2.88
28	19.7	10.1	15.1	765.7	76	4.2	1.67	08	385	2.7		3.00
29	21.0	11.0	14.5	765.7	75	7.9	1.79	111	336	22.5	2.5	
30	20.7	11.2	13.6	766.6	77	9.2	2.14	312	331	2.4	4.4	
Sum											84.7	
Mean	21.6	8.9	14.9	767.0	64	6.6	1.96	111	451	5.0		4.59

Note:

Since each Volume in these series may not comprise the same number of issues, a serial number will, from now on, be also indicated on the front cover. The present issue is the 6th in the series. As for the previous issues:

Volume I,	number 1,	February 1959	- Serial no: 1
Volume I,	number 2,	July 1959	- Serial no: 2
Volume II,	number 1,	June 1960	- Serial no: 3
Volume II,	number 2,	March 1961	- Serial no: 4
Volume III,	number 1,	March 1962	- Serial no: 5
Volume III,	number 2,	present issue	- Serial no: 6

SOME FEATURES OF THE H DAILY VARIATIONS AT ADDIS ABABA

PIERRE GOUIN

INTRODUCTION

The present study describes some features of the Sq diurnal variation of the horizontal component (H) of the magnetic field as observed on five years of magnetic records taken at Addis Ababa, Ethiopia. The period concerned covers almost one half of a sunspot cycle from a maximum monthly mean Zurich sunspot number $\bar{s}$ = 202.8 in January 1958 to a minimum $\bar{s}$ = 19.3 in January 1963.

The position in latitude of the station at Addis Ababa is:

Geographic latitude : North 09°02'
Geomagnetic latitude : North 05°
Magnetic latitude : South 0.5° (Note: A printing error in the Bulletin of the Geophysical Observatory, vol.1.no.1. page 14, indicated North rather than South 0.5° magnetic latitude). Field magnetic surveys by Gouin and Mohr (1961-1962) placed the zero-dip equator (Z=0), at ground level, some 60 kilometers north of Addis Ababa.

Addis Ababa is situated between the magnetic zero-dip and geomagnetic equators and is also directly under the influence of the overhead equatorial electrojet current. If a longitudinal distribution of intensity is accepted for the electrojet (Rastogi 1962), then Addis Ababa is somewhere in the intermediate intensity portion.

I - FORMS OF Sq DIURNAL VARIATION

A - Most common types

Figure 1 represents the most common types of diurnal variation in H observed on the records of Addis Ababa. Because of the situation of the station at the periphery of the ionospheric current systems of both hemispheres, it is expected that the H-trace be sometimes influenced by either one of these systems. Hence, following the classification of typical northern and southern

* Presented at XIII[e] General Assembly of the International Union of Geodesy and Geophysics, in Berkeley, California, Sept. 1963.

types of H-curves adopted by Onwumichelli (1959) for Nigeria, the following are found at Addis Ababa:

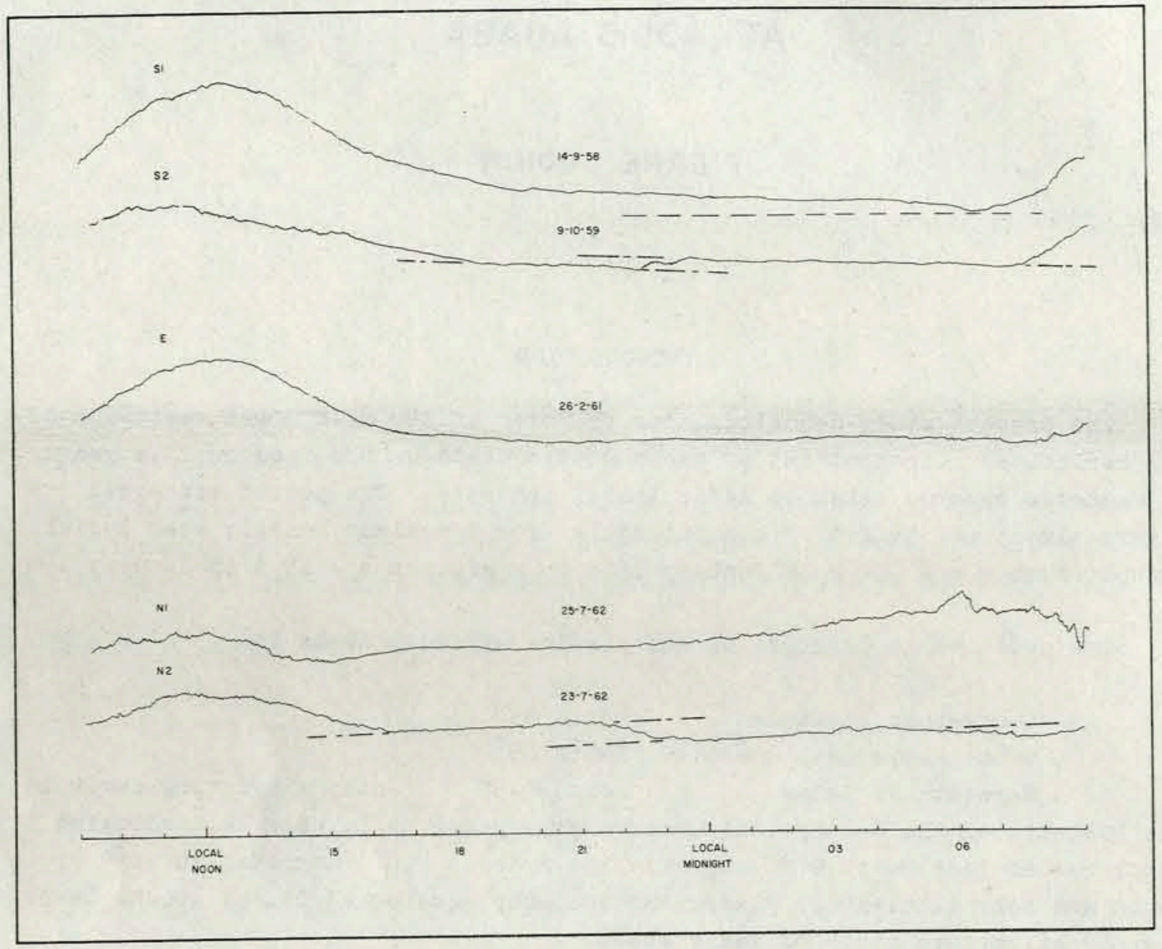


Fig.1 Records showing influence of Southern or Northern hemisphere ionospheric currents on diurnal Sq variation in H at Addis Ababa.

a) Southern type of H-diurnal variation (Fig.1, S1 and S2).

These curves start normally by a minimum, often a marked dip, about sunrise, reach their maximum around LT1100 and then decrease gradually throughout the afternoon and night hours till the next sunrise minimum. The negative night gradient partly depends on the range of the day. A night bay or two may change the level of H, but does not necessarily disturb the gradient of the curve (S2).

This type of diurnal variation was most common during 1958 and the first half of 1959, but its frequency of occurrence has since decreased and is much lower in 1963.

b) Equatorial type of H-diurnal variation (Fig.1,E)

This curve as that of type (a) starts with a minimum around sunrise and reaches its maximum about LT1100, but the afternoon slope is steeper and the

night level is reached at sunset or shortly before or after. All other factors eliminated, the p.m. gradient should be somewhat less steep than the a.m. due to different ionization and recombination a.m. and p.m. rates in the ionosphere.

c) Northern type of H-diurnal variation (Fig.1, N1 and N2).

This curve is quite different from the two previous types. The day's minimum departure sometimes occurs as early as LT1500 of the previous day; H rises gradually during the night towards the next day's noon maximum. The gradient may reach over 8 gammas per hour. Few examples of this type occurred during 1958 but they have since become more common.

Not all H-records are perfect examples of these S,E, or N types. Often, because of other factors distorting the shape of the H-trace, only the gradient of the night slope may give a clue to the type of influence present.

It is of importance to note that the type of Sq variation (N,S, or E) may change from day to day, thus indicating a day-to-day shift in position of the overhead currents.

No particular time of occurrence for H-maximum during the day is shown by any of these three types, but seasonal variations in the time of occurrence of ΔH maximum and ΔH minimum have been found and are illustrated in Fig. 4 and 6.

Onwumichelli (1959) has given a quantitative expression for the asymmetry observed on the N and S types of curves in Nigeria, based on the sunrise (H_r) and sunset (H_s) levels and the range (R') of the day:

$$A_s = \frac{H_s - H_r}{R'}$$

The index A_s has been calculated for some 70 curves of Addis Ababa and it ranges from +0.349 to -0.394. Such a difference would correspond in Nigeria to records obtained at stations as far apart as 4°. Although many more data are necessary before this index, which is found valid for the records of different stations at different latitudes in Nigeria, could be used as an indication of the precise position of Northern or Southern hemisphere currents relative to one singe station, it is, however, certainly indicative of a possible day-to-day shifting of overhead currents over Addis Ababa.

B - Less common types

Fig. 2 shows three records in which the H-traces are of completely different shapes.

Trace A represents an equatorial diurnal variation curve.

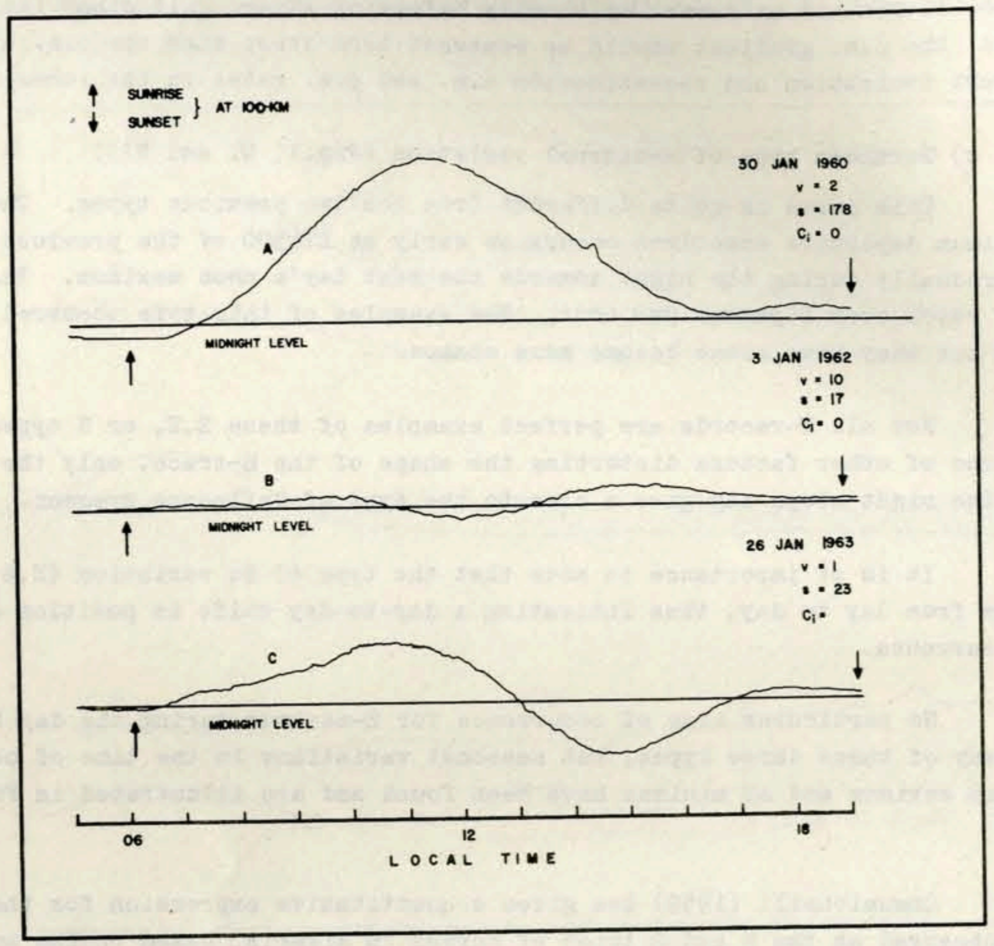


Fig.2 Less common types of Sq diurnal variation in H.

In trace B, the morning rise and the afternoon decline are similar to those of curve A, but the noon maximum has been reversed (Gouin 1962). Such a curve would be normal at latitude 40°. If an amplified L-effect is eliminated as a possible cause of such a reversal (Onwumichelli 1963) and a solution is sought in ionospheric currents patterns, one may imagine an overlapping, at slightly different heights, of the Northern and Southern hemisphere currents: the resultant variation current would preduce, at ground level, this type of H-trace.

Trace C is different again: the a.m. deviation from night level is positive and the p.m. is negative. Bartels and Johnston (1940) labelled similar H-traces at Huancayo as "Big-L days". Without discussing here the possibility of such amplified L-effects, one has to imagine that the resulting current responsible for such a curve has a variation vector eastward during the a.m. and westward during the p.m. hours. Furthermore, during these days (January 1963) Z has been observed to decrease numerically and D to tend towards the East, with increase of H.

Such changes in the shape of the basic H-variation curve occur during the Northern Winter months (especially in January and February) when the zenith angle

of the sun is maximum, i.e. up to 32° South of the latitude of Addis Ababa.

These less common curves sometimes appear for 5-7 consequetive days, do not necessarily develop gradually, and their maximum positive or negative deviations do not always correspond in time to the expected theoretical maximum L-effect. Their sequence may be interupted by a normal Sq curve with or without electrojet amplification.

II - SEASONAL VARIATION

One method of illustrating seasonal effects on the amplitude of the diurnal variation is a contour map of daily inequalities after Gettemy (1962). For the sake of comparison, the same method of grouping has been used for Addis Ababa as for Koror. Mean hourly departures have been calculated for groups of about ten days (three groups of equal weight per month) and moving averages follow a periodicity of 3. Such a periodicity somewhat eliminate L-effects from the mean 30-day curves. All days were used with the exception of a few much disturbed days such as February 11 and 12, 1958.

An initial contour map of inequalities from daily means, with contour levels of 25 gammas, has been drawn for the five years concerned. During the first years, seasonal variations showed up very clearly, but with the decrease of solar activity the number of contour-lines passed from 5 to 2 and seasonal features almost disappeared. To illustrate this point differently, Table 1 shows the decrease in range of ΔH at vernal Equinox during these years, the monthly means being centered on April 5, the nearest point to sun transit at zenith above the station.

TABLE I

ZURICH MEAN SUNSPOT NUMBERS $\bar{s}$ AND H MONTHLY RANGES CENTERED ON APRIL 5

	1958	1959	1960	1961	1962
$\bar{s}$	206.6	172.1	133.5	66.1	50.8
A	145	126	104	82	74
R'	173	167	137	116	94
R"	125	118	92	82	73

Note: - for the definition of ranges A, R', and R", see below under Ranges.

On that map, the morning zero-contour (or the mean value for the day) centered on LT0815 with a tendency to occur later during the summer (Note: the expression Winter and Summer, in this paper, always refers to seasons of the geographic north hemisphere). In 1960, it wandered between 0800 and 0900.

The p.m. zero-contour was located between 1700-1800 in 1958, 1600-1700 in 1959-1960, and then became unstable between 1500-1700 in 1961-1962, with also a tendency to appear later during the June solstitial months.

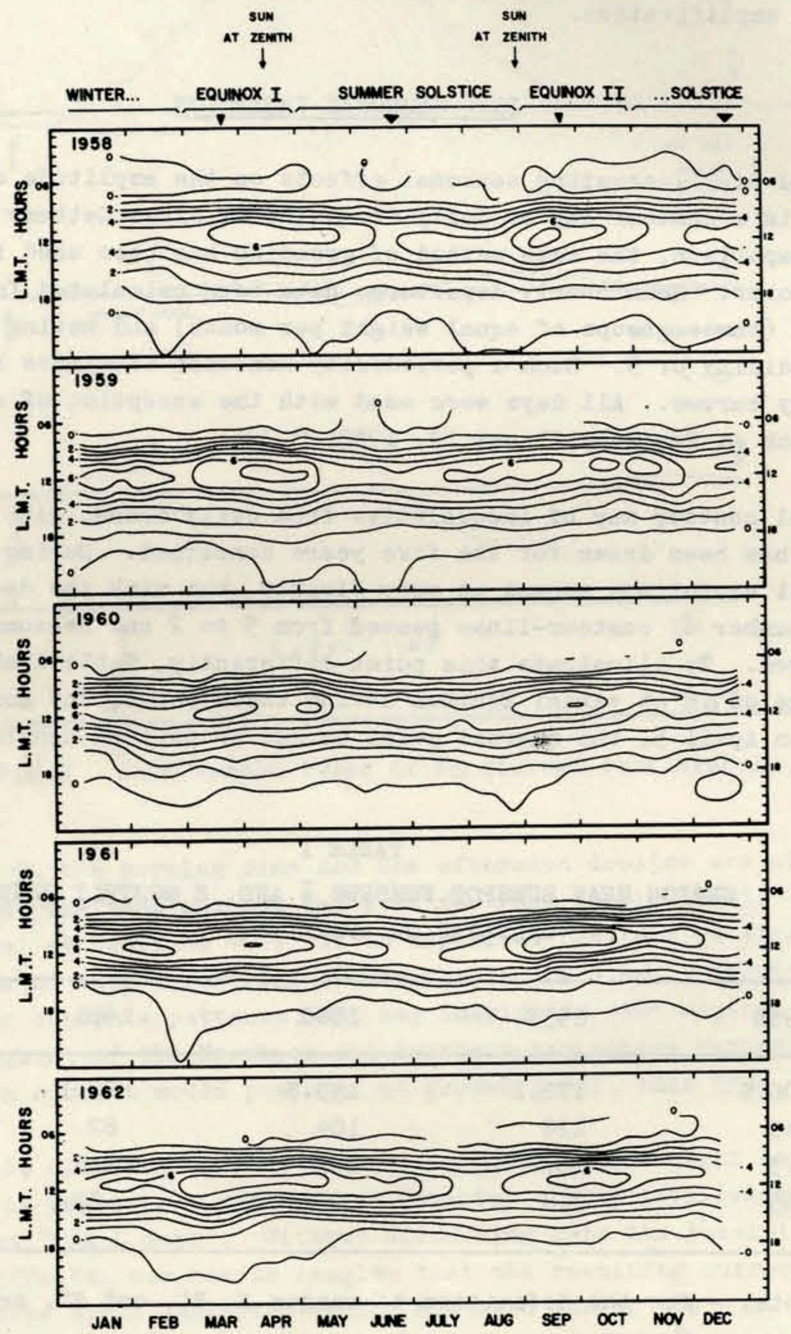


Fig.3 Contour maps of hourly departures in H from mean local mid-night values. Contour levels normalized to the four first months of 1958.

Fig. 3 is a contour map of mean daily inequalities with reference to the mean local midnight value for each group concerned. The values for the contour levels have been normalized to those for the first four months of 1958 and made proportional to the index of solar activity. The contour value is 25 gammas for the first four months of 1958 and is afterwards decreased by 1 unit every four months. Contour lines are simply numbered by order.

One striking feature in Fig. 3 is the clear appearance of the maximum departure of H at the equinoxes. These maxima are not always absolutely centered in the middle of the equinoxes, but are more or less regular according to the magnetic disturbances of the period. For instance, the maximum at equinox II in 1959 is broken up into three peaks, and that of Equinox I in 1961 is short in length and preceded by an unusual maximum in January. The pattern, however, is always present and almost perfect during a year as quiet as 1962.

A clear minimum appears during summer, and winter values occupy a middle position. Details on seasonal variations in ranges and time of occurrence for ΔH-maximum and ΔH-minimum are given below.

Zero-contour lines: the upper and lower frame at 0000 and 2400 hours, in each chart, are zero-contours and the space between them and other zero lines represents portions of the H-trace below midnight level. The morning zero-contours around 0700 is quite erratic throughout the five years. A clear sunrise dip below zero appears during most of 1958 with the exception of the summer months, and during the last months of 1962. Its more irregular appearance during the summer months shows a trend in the sunrise curve towards a smoother gradient.

The post-sunset zero-contour is always present, but its time of occurrence is quite irregular between 1700 and 2400; this irregularity is partly due to the slight slope of the night trace. Trends only, but no clear patterns for the time of occurrence of the post-sunset zero repeat from year to year.

Time of occurrence of ΔH - maximum:

The Graph (Fig. 4) shows three sets of curves for each year:

1. -H (solid line) - Monthly mean time of occurrence of ΔH maximum.
2. -H (dotted line) - A highly smoothed curve derived from (1).
3. -T -Time of occurrence of the sun's transit over Addis Ababa, or apparent solar noon.

At first sight (Curve H), it appears that the maximum deviation in H usually occurs later in summer than in winter time. If this curve is highly smoothed (dotted H), it tends to parallel the sun's transit time curve (T) with a clear tendency to approach it in summer (i.e. later occurrence of ΔH maximum) and to depart from it towards an earlier occurrence in winter.

Essentially, the mean smoothed value for the time of occurrence of H maximum deviation always preceeds the sun's transit by a maximum of 90 minutes to a minimum of about 10. The monthly mean departures (unsmoothed) range from -105 minutes to +40 minutes.

Time of occurrence of morning ΔH - minimum:

In general, the Sq variation in H starts with a morning minimum about sunrise. The shape of the curves may be distorted by Northern or Southern currents, but this influence is not always strong enough to obscure the morning minimum when the curves are drawn from monthly means.

Fig. 5 shows the variation in shape and level from midnight value of the sunrise monthly mean curves. There is no definite pattern for the variations in shape or in level of these curves, except that the morning dip is more pronounced during September and October.

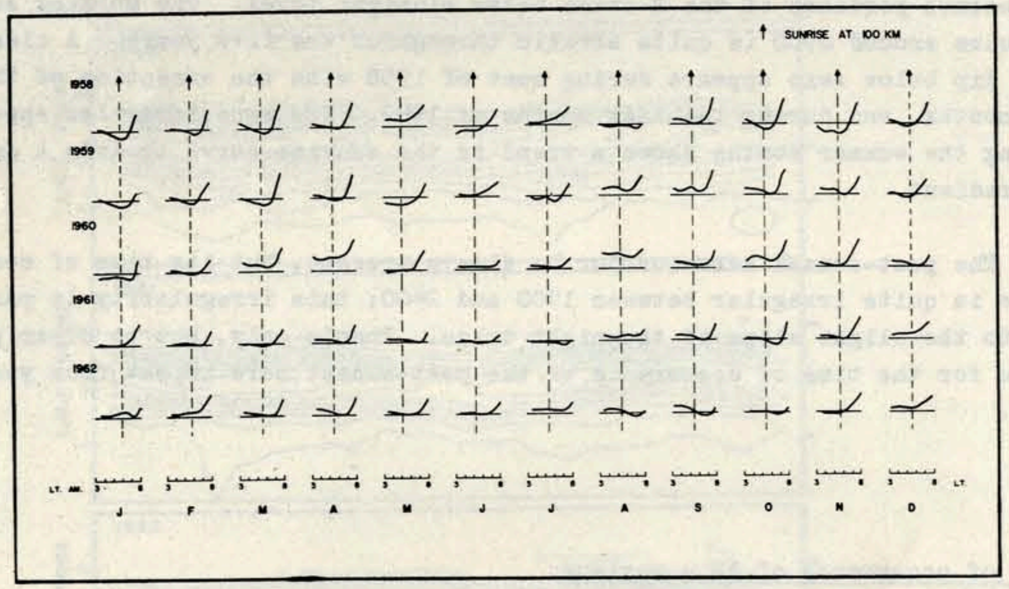


Fig.5

Fig. 6 gives the monthly mean time of occurrence of the morning minimum. Contrary to the ΔH-maximum time of occurrence, neither the broken curve of the monthly mean values, nor its highly smoothed derivative tend to parallel the sunrise time curve. However, each year, the periodicity is successively earlier, with an apparent annual recession such that a complete cycle would occur over 7 to 8 years. The peak of earliest morning minimum occured in July in 1958, about June in 1959, April-May in 1960, February in 1961, overlapped December 1961 and January 1962, and then appears in November-December by the end of 1962.

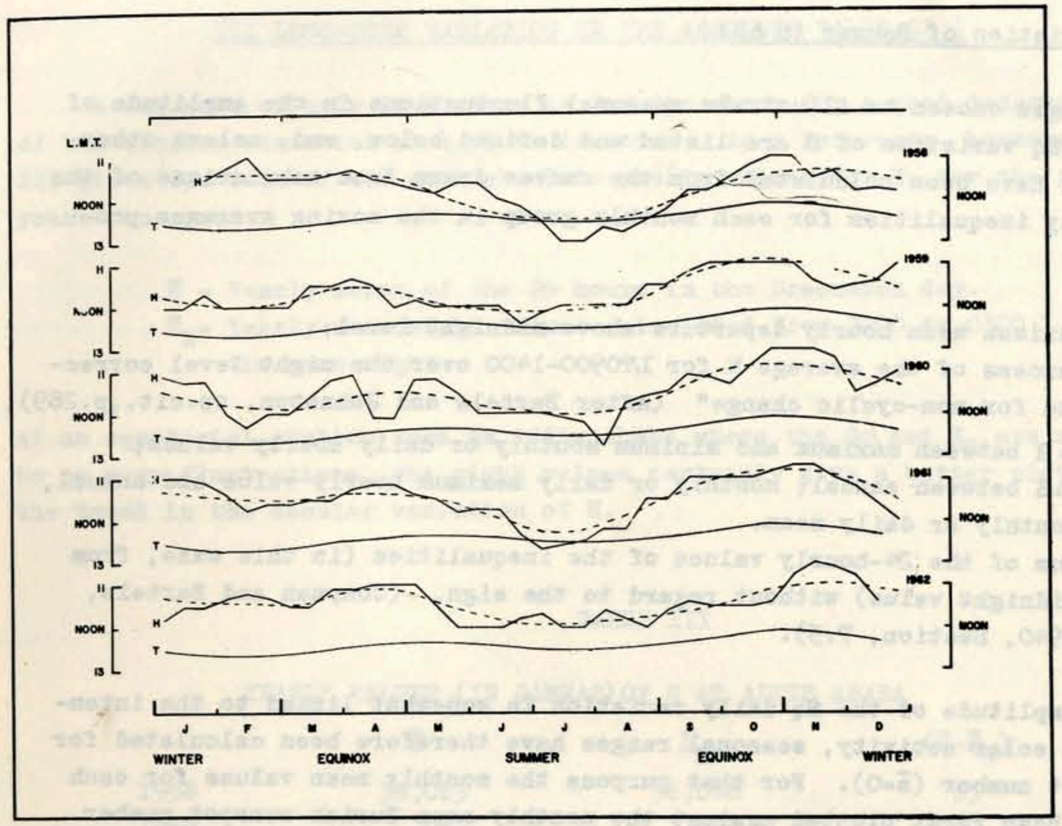
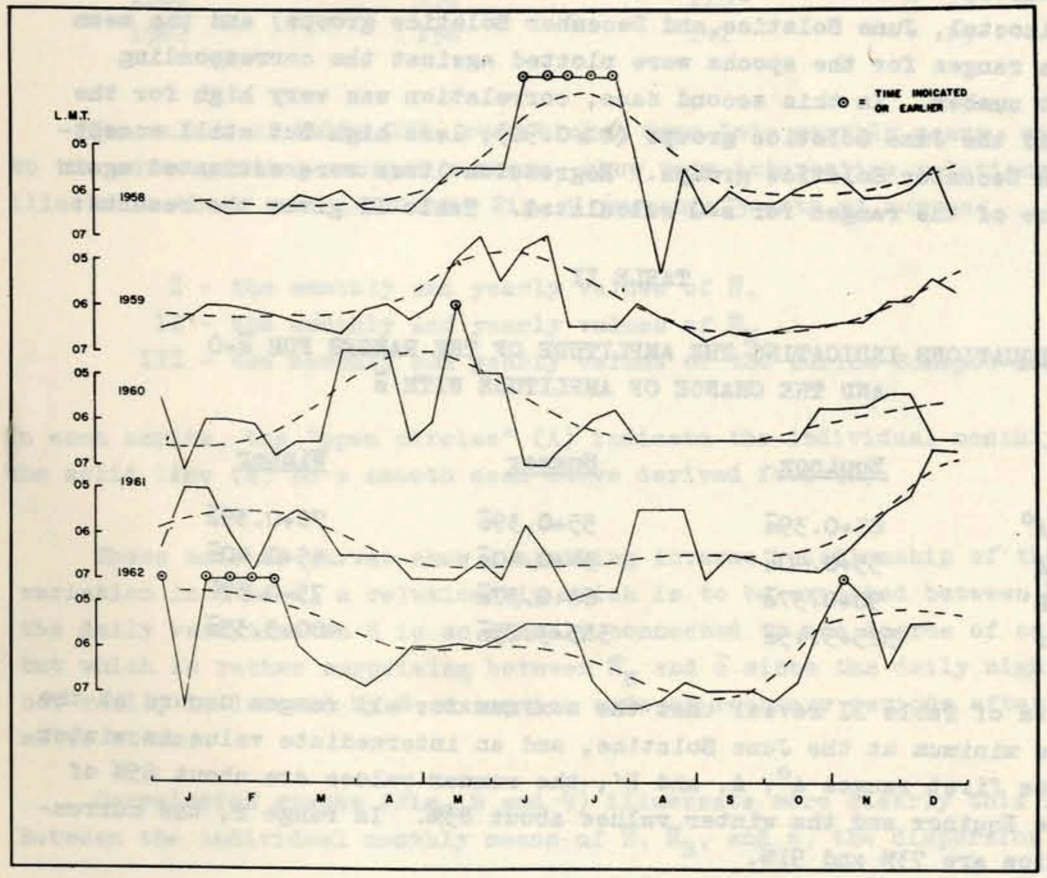


Fig.4 Time of occurrence of ΔH maximum at Addis Ababa.



Seasonal Variation of Ranges in ΔH:

The ranges chosen to illustrate seasonal fluctuations in the amplitude of the diurnal Sq variation of H are listed and defined below, and, unless otherwise stated, have been calculated from the curves drawn from tabulations of the mean 24 daily inequalities for each monthly group in the moving averages process:

A^o = maximum mean hourly departure above midnight level;

A = "excess of the average H for LT0900-1400 over the night level corrected for non-cyclic change" (After Bartels and Johnston, op.cit.,p.289);

R' = ΔH between maximum and minimum monthly or daily hourly values;

R" = ΔH between annual, monthly or daily maximum hourly value and annual, monthly or daily mean.

r = sum of the 24-hourly values of the inequalities (in this case, from midnight value) without regard to the sign. (Chapman and Bartels, 1940, Section, 7.3).

Since the amplitude of the Sq daily variation is somewhat linked to the intensity of the solar activity, seasonal ranges have therefore been calculated for zero sunspot number ($\bar{s}$=0). For that purpose the monthly mean values for each range have been first plotted against the monthly mean Zurich sunspot number ($\bar{s}$) and regression lines have been calculated. Since the dispersion from monthly means curves was rather high then, the months were grouped in standard epochs (Equinoctal, June Solstice, and December Solstice groups) and the mean value of the ranges for the epochs were plotted against the corresponding mean sunspot number. In this second case, correlation was very high for the Equinoxes and the June Solstice groups ($r \geq 0.90$); less high but still acceptable for the December Solstice groups. Regression lines were estimated again and the value of the ranges for $\bar{s}$=0 calculated. Table II gives the results:

TABLE II

EQUATIONS INDICATING THE AMPLITUDE OF THE RANGES FOR $\bar{s}$=0 AND THE CHANGE OF AMPLITUDE WITH $\bar{s}$

	Equinox	Summer	Winter
A^o	$83+0.39\bar{s}$	$55+0.39\bar{s}$	$70+0.39\bar{s}$
A	$55+0.40\bar{s}$	$34+0.40\bar{s}$	$45+0.40\bar{s}$
R'	$90+0.37\bar{s}$	$61+0.37\bar{s}$	$75+0.37\bar{s}$
r	$525+3.45\bar{s}$	$385+3.25\bar{s}$	$480+3.35\bar{s}$

The data of Table II reveal that the maximum for all ranges occurs at the Equinox, the minimum at the June Solstice, and an intermediate value in winter. For the three first ranges A^o, A, and R', the summer values are about 65% of those at the Equinox and the winter values about 83%. In range r, the corresponding ratios are 73% and 91%.

III LONG-TERM VARIATION IN THE ABSOLUTE VALUE OF $\bar{H}$

A sequence of only five years is far too short for a good determination of the secular variation at a given location. As a reference, however, Table III gives two sets of the mean absolute yearly values for H, for the five years concerned:

$\bar{H}$ = Yearly means of the 24 hours in the Greenwich day.

$\bar{H}_N$ = Yearly mean night values calculated from 2200 to 0300 L.T. of the same night.

At an equatorial station such as Addis Ababa where the Sq and S_D are subject to so many fluctuations, the night values certainly give a better picture of the trend in the secular variation of H.

TABLE III

YEARLY VALUES (IN GAMMAS) OF H AT ADDIS ABABA

	$\bar{H}$	$\bar{H}_N$	$(\bar{H}-\bar{H}_N)$
1958	36,083	36,048	35
1959	082	052	30
1960	101	078	28
1961	132	113	19
1962	156	141	15

The values of Table III, even broken down into monthly means, when compared to the corresponding sunspot numbers, show very interesting relationships. To illustrate these relationships, Fig. 7 presents 3 sets of curves:

I - the monthly and yearly values of $\bar{H}$,
II - the monthly and yearly values of $\bar{H}_N$,
III - the monthly and yearly values of the Zurich Sunspot numbers.

In each series, the "open circles" (A) indicate the individual monthly means, the solid line (B) is a smooth mean curve derived from (A).

These sets of curves show a striking inverse relationship of the long-term variation in H to s, a relationship which is to be expected between $\bar{H}$ and $\bar{s}$ since the daily variation in H is so closely connected to the degree of solar activity, but which is rather surprising between $\bar{H}_N$ and $\bar{s}$ since the daily night level is not really influenced by S, exception made of recovery periods after strong magnetic storms.

Correlation graphs (Fig. 8 and 9) illustrate more clearly this relationship. Between the individual monthly means of $\bar{H}$, $\bar{H}_N$, and $\bar{s}$, the dispersion, as expected,

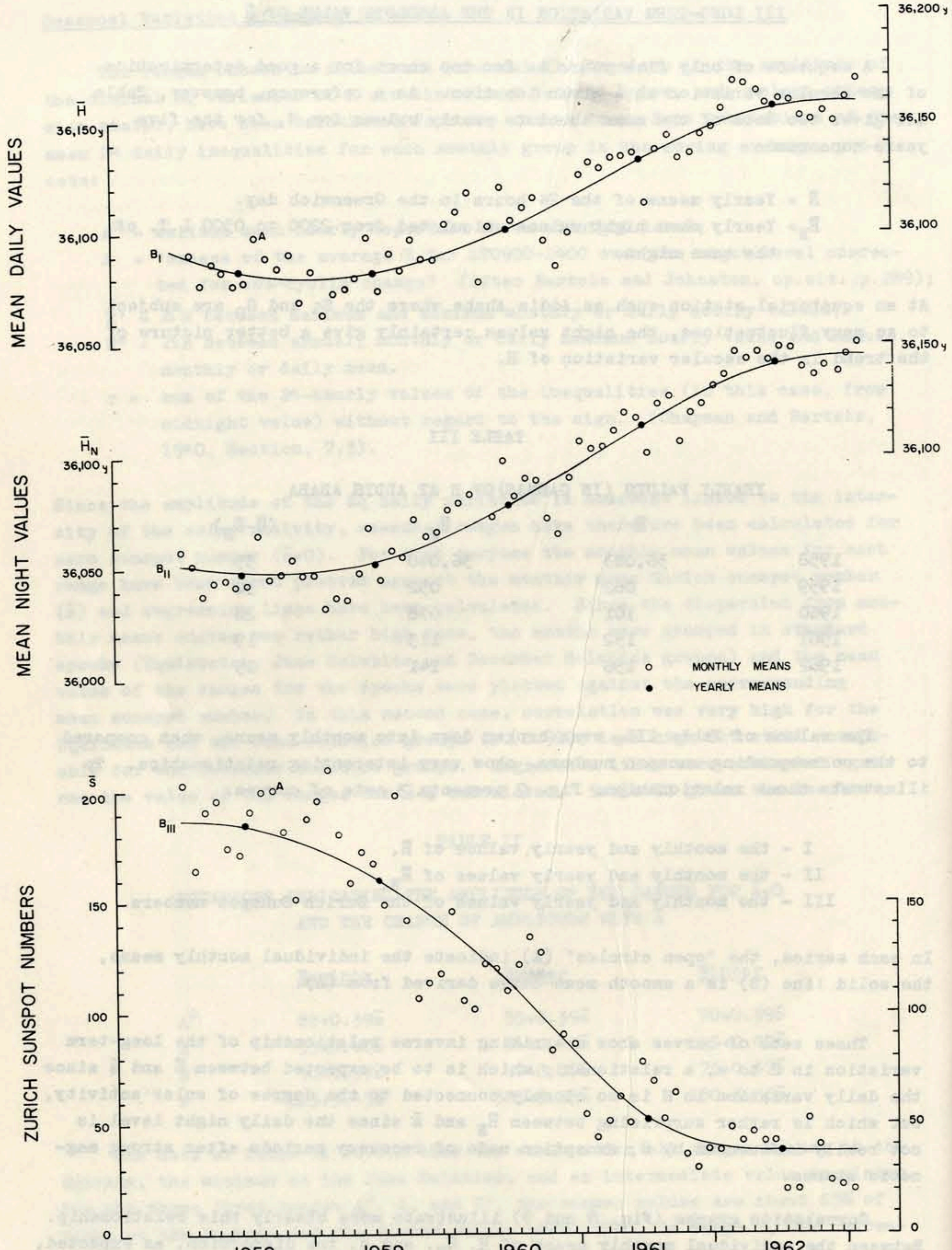


Fig.7 Correlation between long-term variation in H and Zurich sunspot numbers.

is rather high; when the derived values (triangles on the graphs) are plotted, a coefficient of correlation = 1 appears for B_I vs B_{III} between 50-150 $\bar{s}$, and between 55-160 $\bar{s}$ for B_{II} vs B_{III}. This means that in Addis Ababa, during the period when $\bar{s}$ stayed within 50-160, the rate of change of the mean absolute value of H varied inversely as the solar activity. Both extremes of the graphs, however, i.e. below 50 and above 150-160 $\bar{s}$, show a positive deviation of $\bar{H}$ with respect to s as if, for one thing, during these extreme periods, the degree of disturbance which always tends to lower the general level of H were less then during the more normal period when $\bar{s}$ stays between 50-150.

It is also of interest to note that the difference $(\bar{H}-\bar{H}_N)$, from year to year, is also directly proportional to the sunspot number of each year.

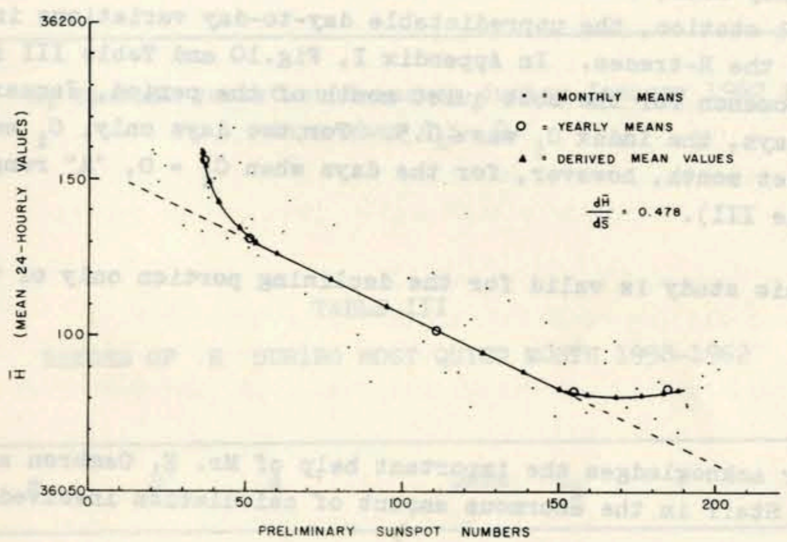


Fig. 8. Correlation between the mean value of H and sunspot numbers.

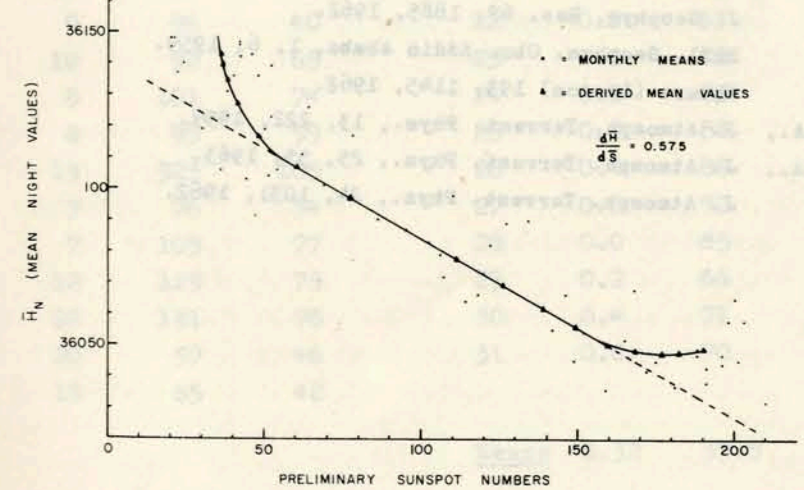


Fig. 9. Correlation between the mean night value of H and the sunspot numbers

CONCLUSIONS

This study, as presented, is in many ways incomplete:

1) It intentionally presents the bare results of the analysis of the H-traces as recorded at Addis Ababa without any special effort to give a physical interpretation of the phenomena described. A similar analysis is being made for D, Z, and F; it seems more logical to look for a suitable interpretation when the total magnetic field variations is analysed.

2) All the data analysed in this paper are based on moving averages, or monthly and yearly means. Curves and Tables show monthly, seasonal, and even secular trends; they mask, however, a very important characteristic of the Sq-curves at an equatorial station, the unpredictable day-to-day variations in range and often in shape of the H-traces. In Appendix I, Fig.10 and Table III illustrate this day-to-day phenomenon for the most quiet month of the period, January 1962, during which, for 24 days, the index C_i was ≤ 0.5. For two days only, C_i was = 1.0. During such a quiet month, however, for the days when $C_i = 0$, "A" ranges from 5 to 117. (see Table III).

3) This study is valid for the declining portion only of the present solar cycle.

Acknowlegments

The author acknowledges the important help of Mr. E. Cambron and of the other members of the Staff in the enormous amount of calculation involved in this paper.

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Appendix:

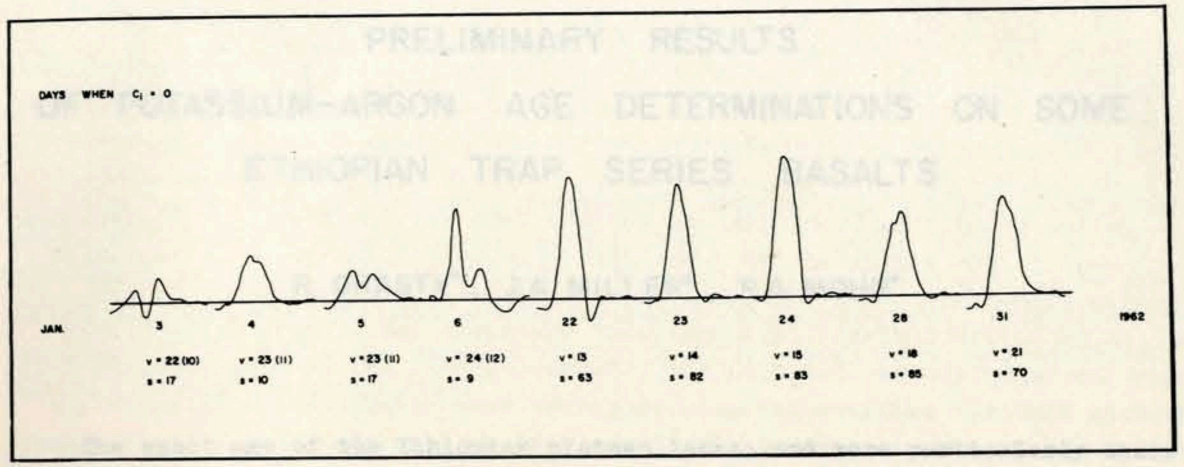

Fig.10 Sq diurnal variation H-curves during January 1962 for all days when $C_i = 0$.

TABLE III

RANGES OF H DURING MOST QUIET MONTH 1958-1962

JANUARY 1962

Date	C_i	s	R'	A	Date	C_i	s	R'	A
1	0.2	27	76	54	17	0.1	16	103	68
2	0.5	23	69	36	18	0.1	22	89	58
3	0.0	17	34	5	19	1.1	29	126	24
4	0.0	10	49	41	20	0.1	34	82	67
5	0.0	17	36	23	21	0.5	42	117	92
6	0.0	9	96	40	22	0.0	63	132	99
7	0.2	10	92	65	23	0.0	82	111	90
8	0.1	8	101	74	24	0.0	83	140	117
9	0.4	8	95	59	25	0.2	88	123	101
10	1.8	13	325	105	26	0.4	86	143	92
11	0.7	7	76	54	27	0.6	92	92	64
12	0.1	7	105	77	28	0.0	85	85	59
13	0.1	12	119	79	29	0.2	66	103	68
14	0.9	28	131	78	30	0.4	71	89	74
15	0.6	20	57	46	31	0.0	70	104	82
16	0.6	19	65	42					
					Means	0.32	37.5	84	65.6

PRELIMINARY RESULTS OF POTASSIUM-ARGON AGE DETERMINATIONS ON SOME ETHIOPIAN TRAP SERIES BASALTS

R. GRASTY*, J.A. MILLER+, P.A. MOHR+

The exact age of the Ethiopian plateau lavas, and more particularly their precise lower age limit, has been a matter for speculation ever since Blanford (1869) first succeeded in recognising fundamental stratigraphic and petrographic sub-divisions within this immense volcanic province. Although the basis for Blanford's classification has since been modified (Dainelli 1943), Mohr 1962b), his original terminology is retained in the following table:

Aden Series	(4.	fissure olivine basalts, extremely scoriaceous
	(3.	central basalts, peralkaline silicic lavas and pyroclasts
	(major Rift faulting, with contemporaneous undersaturated lavas)	
	(2.	Magdala Group
	(	central basalts, usually porphyritic and amygdaloidal, and more-silicic lavas and pyroclasts, with sedimentary intercalations and lateritisation. Some minor intra-formation unconformities.
Trap Series	(	Conformable on:
	(1.	Ashangi Group
	(	fissure basalts, generally non-porphyritic, with some thick basaltic agglomerates. No silicic lavas, nor sedimentary intercalations.

The evident pre-Rift System age of the Trap Series, which forms by far the greater bulk of the Ethiopian volcanics, has proved difficult to fix within close limits on the basis of the available palaeontological, stratigraphical and tectonic evidence. It is certain that the Series is post-Lower Cretaceous (lying upon regressive sandstones of Aptian age in Arussi) and pre-Pliocene (overlain by Pliocene marine sands in northern Afar), but within this wide time range two possibilities have received support: most non-Italian authors have compared the Ethiopian volcanic province with that of the Deccan Traps, and because of several superficial resemblances, especially that of bulk development, have propounded a common age for both. Therefore such workers as Blanford (1869), Stefanini (1936), Swartz

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and Allen (1960), Krenkel (1957) and Abul-Haggag (1961) have considered that volcanic activity in Ethiopia and Yemen, as in the Deccan province, commenced in the Upper Cretaceous and continued on into the early Eocene. Recent absolute age determinations have confirmed this time range for the Deccan basalts (Miller and Mussett 1963b).

On the other hand, some Italian authors have related the initial vulcanism in Ethiopia to the uplift of the Arabo-Ethiopian Swell, the crest of the swell fissuring along meridional tensional lines and permitting the ascent of hot, fluid magma to the surface. The uplift of the Swell was largely accomplished during the Upper Eocene (Dainelli 1943, Beydoun 1960), and on this basis Dainelli considers that the earliest Trappean eruptions were end-Eocene, with major activity continuing throughout the Oligocene, and on into the Miocene in southern Ethiopia where palaeontological evidence (Arambourg 1943) fixes a definite Lower Miocene age within the Series.

This second hypothesis has found support from some later workers (Furon 1963, Mohr 1962b) who have emphasised that both the tectonic environment and the petrology of the lavas of the Deccan Traps are quite distinct from those of the Ethiopian lavas. The petrochemical evolution of the Ethiopian lavas in relation to their tectonic environment has been discussed by Mohr (1963). It is sufficient here to state that whereas the Deccan basalts are tholeiitic in composition and are regionally associated with a lateral ridge of the Indian Ocean, the Ethiopian basalts are alkali basalts typical of the oceanic type Swell-Rift environment in which they occur.

The present work was undertaken to attempt to confirm one or other of the two hypotheses summarised above, despite the meagre number and variety of available specimens. Potassium-argon determinations were made on seven basalts following the precedures summarised by Miller and Mussett (1963a). These basalts included five specimens collected by the Imperial College, London, students' expedition to Ethiopia, from the Abbai gorge section along the Addis Ababa - Debra Markos road, a single basalt from Gedaref, Sudan. The Abbai basalts all belong to the Ashangi Group, which is thinly developed in this region (the Magdala Group is entirely absent) as six thick fissure flows with some intervening agglomerates all resting with slight unconformity on Upper Jurassic marine limestones, evaporites and sandstones. The Omo basalt occurs about the middle of a thick succession of Magdala Group lavas, and it is considered on the basis of petrography and regional occurence that the Gedaref basalt also belongs to this Group.

The essential petrographic characteristics of the Ashangi and Magdala basalts are now well-known (see Comucci 1950, Hieke Merlin 1950, Mohr 1963). The Abbai basalts are typical Ashangi basalts, excepting their appreciable olivine content. They are all black, dense, non-porphyritic lavas with a fine grained sub-trachytic texture formed of labradorite-bytownite laths (0.02-0.2mm), subeuhedral pale titanaugite and clusters of fresh olivine grains. Ilmenite is abundant as skeletal rods and magnetite is commonly present, to the extent that the total iron-ore content is high even for a basalt; this agrees with the observation of a high degree of oxidation in the Ethiopian lavas in general (Mohr 1963). Patches of red-brown devitrified glass are fairly common. Apatite is a rare accessory.

The Omo basalt is a coarsely prophyritic olivine-augite basalt, the olivine phenocrysts being typically magnesian and zoned. Olivine is abundant in the groundmass and shows iddingsitisation. Phenocrysts of green augite up to 5mm in length contrast with the pale second generation clino-pyroxene. Plagioclase is confined to the groundmass as tabular crystals of labradorite. Magnetite and ilmenite are again very abundant.

The Gedaref basalt is a pale-grey, relatively light rock composed of poorly crystallised labradorite laths (0.05-08mm) with abundant pale augite and rounded olivine grains. The olivine is also present as somewhat larger (1-2mm), partially iddingsitised grains. Magnetite is only moderately abundant and ilmenite is rare.

All seven basalts, therefore, are typical alkali-olivine basalts such as characterise the volcanic province of the Arabo-Ethiopian Swell. Table 1 lists the analytical data obtained for these specimens. In view of the petrochemical significance of alkali content in basalt Na_2O was determined along with K_2O.

Despite the scatter of obtained ages for the Abbai basalts the preliminary indication from an average value is a late Eocene age. Therefore, with due consideration given to experimental error and the possibility of argon loss (Miller and Mussett 1963a) the thesis of G. Dainelli is supported, though the first fissure eruptions along the Abuya Mieda line which supplied the Abbai region flows probably occured during uplift of the Arabo-Ethiopian Swell rather than at its termination in the early Oligocene. Preliminary results from field studies of basalt flow inclinations in relation to the Swell surface also support a post-uplift age for the Ethiopian Trap Series (Grabham and Black 1925, Dainelli 1943).

The single dates for the Magdala lavas from Gedaref and the Omo gorge may tentatively be taken to support Dainelli's postulate that the upper part of the Trap Series is younger in southern Ethiopia than to the north, extending beyond the Oligocene up into the Lower Miocene.

The general scheme for the temporal-tectonic relations of the Trap Series as enunciated by Dainelli (1943) is therefore confirmed by the present work. It is hoped in a future programme to determine the precise age limits of the Ashangi and Magdala Group lavas, the Rift carbonatites and the Aden lavas, so as to obtain a better understanding of vulcanicity in relation to the tectonic history of the

Horn of Africa, and endeavour to fix more precise age limits to the Rift faulting of Afar and the Main Ethiopian Rift.

Acknowledgements

The authors' thanks are due to Miss Daphne Bate who made the alkali determinations on the basalts, and to Dr. S. O. Agrell for preparing thin sections of these rocks.

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Table 1. Results of K/A age measurements

Sample	Reference	K_2O per cent	Atmos. contam. per cent	Vol. of A^{*40} / Wt. of sample (gm)	Apparent age (m. yrs)	Average apparent age (m.yr)	Standard deviation (m.yrs.)	Mean error (m.yr)	Na_2O per cent	K_2O / Na_2O
Abbai basalts	ETH 33b	1.13	86.6	0.001575	42	)			2.93	0.39
	ETH 28b	1.00	81.4	0.002089	62	)			2.92	0.34
	ETH 26b	1.20	72.7	0.002784	69	) 49	15	7	2.92	0.41
	ETH 25b	0.84	91.2	0.001143	41	)			3.03	0.28
	ETH 24a	0.67	96.0	0.000673	30	)			2.27	0.30
Omo basalt	373	0.97	69.6	0.000811	25				2.05	0.47
Gedaref basalt (Sudan)	S 7	0.43	77.3	0.00474	33				2.70	0.16
Average Ashangi basalt (Mohr 1963)		1.25							2.85	0.42
Average Magdala basalt (Mohr 1963)		1.9							2.9	0.64

$_B = 4.72.10^{-10}$ yr $^{-1}$ $_e = 0.584.10^{-10}$ yr $^{-1}$

Vol. of A^{*40} = Volume of radiogenic argon-40 (mm^3) N.T.P.

THE ETHIOPIAN CAINOZOIC LAVAS

A PRELIMINARY STUDY OF SOME TRENDS : SPATIAL, TEMPORAL, AND CHEMICAL

PAUL A. MOHR*

Introduction

The Cainozoic lavas of Ethiopia form one of the most important volcanic developments associated with the Arabo-African Rift System. In their regional extent, their great thickness and volume, their tectonic and structural associations, and their general petrographic uniformity allied with the minor presence of a great variety of peculiar petrographic types, the Ethiopian Cainozoic lavas are perhaps without parallel. This paper, based on the fairly widespread field-researches of the author and upon the extensive petrological investigations of various Italian authors, attempts to portray some of the more significant features of this very important - and very much neglected - volcanic association.

1. Spatial and Temporal

The great Cainozoic volcanic episode, still in progress, is unique in the crustal history of the Ethiopian region. Both spatially and temporally this episode has been intimately associated with the Upper Eocene uplift of the Arabo-Ethiopian Swell and the Miocene faulting of the Rift System, two tectonic events whose essential inter-relationship has been shown by the author (1962a). Indeed, it is on the basis of the relative positions of the Cainozoic lavas of Ethiopia, both spatially and temporally, to the Rift faulting that the long-recognised distinction is made between the (pre-Rift) Trap Series and the (post-Rift) Aden Series.

(a) The Trap Series

The Trap Series is composed of predominantly basaltic lavas which have the characteristic persistent and uniform extension of flood basalts. These lavas are cut by the rift faulting which they therefore pre-date. They cover a present total area of approximately 600,000 sq.kms., but prior to denudation they must have covered an area at least 150,000 sq.kms. greater. Despite the denudation the greater part of the Ethiopian Plateau and the Rift floor is surfaced by these lavas, where not covered by the more recent rocks of the Aden Series. On the Somalian Plateau the Trap Series is more severely

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restricted in its occurrence to the western fringe, apart from numerous thin isolated outcrops in the Ogaden. The major development of the Trap Series thus lies to the west of the ensuant Rift System, and thins out both south-eastwards into Ogaden and northern Kenya, and north-westwards into Sudan and Eritrea. There are strong indications, however, that the Tertiary lavas of Yemen were contiguous with the Trap Series of Ethiopia before the formation of the Red Sea trough.

Away from the fringes of regional occurrence the total thickness of the Trap Series is found to vary between 200m and 3500m, figures of the latter magnitude owing to late central-type eruptions which built up huge lava shields on the earlier fissure basalts. All the great heights of Ethiopia are formed by the denuded remnants of late-Trappean shield volcanoes (with the exceptions of the pre-Cambrian horsts formed by the rift faulting along the north-western margin of Afar and at the southern end of the Main Ethiopian Rift). Particularly noteworthy are the Simien Mts. of Beghemeder which culminate in Dejen (4620m), and Abuna Yosef, Guna and Abuya Mieda to the South; the Chokkai Mts. of Gojjam, Tulu Wallel in Wollega, the Gughe Mts. in Gamu-Gofa, and the Batu Mts. and Mts. Encuolo and Kakka which lie along the western margin of the Somalian Plateau. Not even one of these great shields has yet been subjected to a proper petrogeological reconnaissance.

No detailed succession nor regional correlation of the flows of the Trap Series has yet been attempted, though this will not prove a difficult task for those with helicopter and aerial photographic facilities such as have been used in the recent survey of the Abbai basin (Jepson 1960). Allowing for any effects of denudation the number of flows in any one region is known to vary from six in the central Abbai basin, through, for example, twelve in eastern Wollega and west of Addis Ababa, a minimum (base not exposed) of thirty in central Afar and of fifty in southern Afar and in northern Jimma, to more than one hundred and twenty on the western side of the Simien shield.

Blanford (1869) divided the Trap Series of north-central Ethiopia into two groups, the Ashangi and Magdala Groups respectively, which he claimed to be separated by an unconformity. Later workers in Ethiopia have not been able to confirm the presence of such an unconformity, even in the region of Blanford's survey (see Merla & Minucci 1938), but unconformities within the Trap Series have been recognised in western Gojjam by Jepson (1960), in southern Wallo by Rogers (1962), and in central Afar (the author). However, these unconformities are usually minor and in any case do not correspond with any marked petrographic changes, as advocated by Blanford; Blanford's recognition of a petrographic succession is not invalidated despite the lack of an unconformity separating the two Groups of the Trap Series, and is summarised below with modifications and additions by the author:

2. Magdala Group - numerous, often thin flows of commonly porphyritic basalts, the individual flows frequently showing marked variations in petrography from one to the next. The basalts of the central-shield volcanoes ally a coarsely porphyritic texture to common amygdaloidal structure, with zeolities, agate and semi-opal filling the amygdales. Both ultrafemic and silicic lavas typify the Magdala Group, the silicic lavas being highly alkaline; interbedding of silicic pyroclasts and various sediments also occurs. Some minor intrusives of late age have formed dykes, sills and occasionally stocks within a shield. Total thickness 0-2600m.

1. Ashangi Group - a relatively small number of sometimes thick flows of dark, compact, non-porphyritic basalts; where porphyritic texture is developed olivine usually forms the phenocrysts, never plagioclase as in many Magdala basalts. No silicic lavas or pyroclasts, nor sedimentary horizons, are developed though basaltic agglomerates and coarse tuffs commonly separate the individual flows. Amygdaloidal structure rare. Total thickness 200-1200m.

It is immediately apparent that there are marked petrographic differences in the associations of the Ashangi Group and the Magdala Group, and it is on this basis that any division of the Trap Series should be attempted. Because the unconformities observed within the Trap Series do not coincide with the petrographic division, no temporal implications are incorporated beyond the obvious sequence at any one locality: Blanford's classification rests on the assumptions that contemporaneous lavas had similar or identical petrography, and that there were two distinct phases of major eruptions separated by a period of regional denudation. Considering the Trap Series over the whole of Ethiopia, and also the Yemen, these two assumptions are found not to hold.

The terms Ashangi and Magdala are therefore used in this paper in the sense that a petrographic division of the Trap Series can be made, an earlier group of fissure basalts being followed without apparent break by central basalts, differentiates, and sedimentary intercalations of the second group. If it is desired to formulate the base of the Magdala Group in a particular region this is taken to be at the base of the first flow of differentiated material; no doubt further studies will be able to provide a datum line based on the appearance of the first central lavas, even if of basaltic composition.

No alternations of Ashangi and Magdala-type basalts are known to occur, but the lack of major unconformities and the chemical similarities (see section 3. below) of the two types of lavas suggest that the Trap Series has a unitary nature. However, in some regions lavas of the Magdala type are not developed, and only Ashangi-type basalts are present as in the central Abbai basin, in northern Hararge and in central and eastern Afar - it must be emphasised that no temporal implication such that volcanic activity terminated earlier in these regions can be proved, though the possibility of this having happened is not unlikely on petrogenetic grounds.

The lavas of the Ashangi Group have the characteristic features of fissure basalts, individual flows of wide regional extent and uniform thickness having been extruded upon a very flat surface; the initial flows were extruded immediately consequent to the Upper Eocene uplift of the Arabo-Ethiopian Swell, with minor unconformity upon a peneplained surface of marine Mesozoic sediments, the lavas progressively overlapping onto older rocks westwards. The ready adaption of the flows to filling any hollows or smoothing out bumps in the pre-existing topography proves their very fluid nature on emission at the surface. These fissure basalts have a very uniform petrography, and superimpose upon one another to give a typical trappean form.

Yet despite the magnificent sections exposed in the great river gorges of the Ethiopian Plateau no evidence has so far been found of any fissure-lines from which these trappean basalts were fed. The very considerable proportion of the gorge-sections which remain unexplored must be taken into account, but even so it is surprising that the known sections have not revealed a single line or centre of volcanic emission. Statistically this factor tells more strongly against fissure-feeders than against pipe-feeders, but in view of the undoubted flood nature of the Ashangi-type basalts it seems probably that the major fissure lines lie east of the river gorges of the Ethiopian Plateau, that is close to the margin of the Rift System and to the central axis of the Arabo-Ethiopian Swell. This might also be inferred from the alignment of numerous Magdala-type centres just outside the margins of the Rift System, both on the Ethiopian and Somalian Plateaux. Further strong evidence for this position of the fissure lines is provided by the observation of dyke-swarms paralleling the Rift margins and about 40-60kms outside them, for example between Mts Badda and Kakka in Arussi and along the crest of Abuya Mieda in Wallo. The immense area covered by Trap lavas in Afar suggests that fissure lines must be situated beneath this region but their location and orientation is not known.

Other fissure-tectonic lines in Ethiopia are suggested by their associations. Thus the great stratovolcanoes of Simien and Guna in Beghemeder lie on a N-S alignment known to be directly associated with faulting (author 1963a). In paralleling the Rift margin to the east this alignment can be continued southwards west of and parallel to the course of the Abbai between its respective confluences with the Bashillo and the Jimma rivers, which is that portion of the Abbai gorge which is peculiarly marked by numerous recent basaltic centres of the Aden Series (see below). Displaced some 70km further west an alignment can be noted from numerous small centres immediately east of Lake Tana, southwards via the Chokkai Mts., the recent basaltic centre of Mt. Boti, to the remarkably linear (and unexplored) section of the Omo river between Abalti and the Gojeb confluence, and thence to the great Magdala centre of Mt. Gughe in Gamu-Gofa.

These postulated immense tectonic-fissure lines may not be continuous, minor lateral displacements having occurred as with the Rift System faulting. Whilst the existence of these lines as feeders for the Ashangi basalts remains hypothetical, yet they help to explain a peculiar feature of the Trap Series in Ethiopia: the greater quantitative extrusion of lava west of the Rift System later to be formed in the Miocene. Other conjectured tectonic-fissure lines are: that running N.N.E. from Tulu Wallel in Wollega, northwards via Mts. Nasi, Waladura and Belaia, and thence along the intensely faulted and injected zone east of Galabat; the Mt. Arato-Tacara line in northern Tigrai and Eritrea (Merla & Minucci 1938); a number of possible N.N.W. lines in Afar, a direction also suggested by the foci of the 1961 Karakore earthquakes; the very evident alignment of the volcanic hills of Marda, running N.N.E. past Jigjiga on the Somalian Plateau.

Altogether, what little evidence is at present available suggests that the Ethiopian Plateau is underlain by a parallel series of roughly meridional tectonic-fissure lines, all now quiescent though some were associated with renewed minor volcanic activity in the Quaternary. On the Somalian Plateau such lines are less evident, apart from the dyke swarms close to the Rift margin, but their trend is probably dominantly N.E. except for some N.N.W. lines in the Harar region.

The alignment of the Magdala centres has already been commented on, as expressed by the situation of the great shield volcanoes. The problem arises as to whether <u>all</u> the lavas of the Magdala petrographic type are of central origin: which is to say that the Trap Series can be simply divided between an earlier fissure basaltic phase and a later central basaltic and differentiate phase in a given region. It is very doubtful that the situation is as simple as this in its details though the overall picture is correct: there are a number of localities where Ashangi-type basalts are known to occur within a thick succession of Magdala-type lavas (but never vice-versa), for example at Addis Ababa and at Ankober (see Gortani & Bianchi 1941; author 1963b, chapter 8). Also some of the basalt flows of Magdala-type petrography (see below) have every appearance, including wide regional extension, of fissure lavas.

The unconformities observed within the Trap Series of Gojjam, Wallo and Afar all occur in the lower part, in flood basalts of the Ashangi type. It is therefore probable that the final movements of the Arabo-Ethiopian Swell uplift had terminated before the period when fissure eruptions were generally superseded by central eruptions, and that this change was not accompanied by a significant hiatus; it is probable that for a time both types of eruption were operating together in different regions. Occasional reversions to fissure eruptions of Ashangi-type basalts occurred within the Magdala sequence. These facts give rise to petrological problems concerning the contemporaneous availability of somewhat different magma types, but this situation is even more acutely encountered in the Aden Series, discussed below, and in any case is subordinate to the fundamental problem of deep-seated magmatic changes during formation of the Trap Series.

Thick pyroclastic horizons are a fairly common feature of the Ashangi-Group. They are composed of dark-coloured basaltic tuffs and coarse agglomerates with bombs, representing an end phase to a particular eruption; there is no evidence that such horizons represent an initial phase to an eruption, thus no pyroclastic formation has yet been found underlying the basal basalt flow in any region of Ethiopia. The occurrence of large, charred fragments of fossil wood in these Ashangi agglomerates is a problem not fully understood, as the pyroclasts show evidence of rapid accumulation with little or no intervening period available for the growth of trees before superposition of the next basalt flow. These agglomerates may be as thick as 20-30m in the central Abbai region, separating basalt flows of roughly the same thickness; this association of thick pyroclasts with fissure basalts is very unusual and cannot be paralleled, for example, in Iceland during the present millenium.

Pyroclastic horizons are much more abundant in the Magdala Group succession, though rarely as thick as the Ashangi agglomerates. They tend to be light in colour, frequently variegated, and with tuffs predominating over agglomerates. There is evidence, in western and northern Shoa, that explosive eruption of silicic ashes preceded as well as followed the extrusion of silicic lavas. The surfaces of the lavas of the Magdala Group commonly show a surface-reddening up to 5cm thick beneath the overlying tuff or lava, with evidence of an appreciable period of intervening weathering, soil-formation, even erosion. Extremely thick developments of pyroclastic rocks within the Magdala Group are found in southern Sidamo, probably derived from explosive eruptions of Mt. Gughe, their total thickness exceeding 700m south of Wondo. At Wondo calcitic horizons are known within this pyroclastic succession.

True sedimentary horizons are a characteristic of the Magdala Group, and the lignitiferous layers which often occur within them were exploited during the Italian occupation (Usoni 1952). These sediments can be of great variety within a single horizon, and commonly include fine sands, clays, fissile mudstones and lignite, as well as less common ochrous soils, black shales, silicified tree-trunks, pumice, and obsidian breccia. Sedimentary intercalations are usually associated with the lavas of central-type volcanoes, the slope of the shield or cone providing for streams in which the clastic materials were transported. The thickness of these sediments may exceptionally reach 20m, but much more typical are values of 3-4m with any contained lignite band(s) rarely exceeding 1m.

The only fossils found within the inter-Trappean sediments of the Magdala Group have been such remains as Nicolia aegyptica, Dicotylophyllum, Helix, Melanopsis and Melania, all of which have too wide a time-range to be of any use for dating the Series. A Burgdigalian mammalian fauna has been found in fine-grained lacustrine sediments near the base of the lava series west of Lake Rudolf, and is used by Dainelli (1943) to imply a somewhat later age for the Trap Series in southern Ethiopia compared with the

earlier extinct or dormant silicic centres, as for example at Alid, Fantale, Boseti-Guda, Zuquala and Alutu. Where the recent basalts occur on the Plateau they have originated from centres which show the meridional alignment mentioned above; they are found, for example, along the bottom of the canyon of the middle Abbai and also a little to the west; also over an extensive region south of Lake Tana, which lake owes its existence to the damming effect of these basalts; also numerous small basalt patches in western Wollega, and a remarkable single flow which has originated close to the summit of Dejen in the Simien Mts. Recent fissure basalts cover much of the southern portion of the Danakil Horst, but unlike the Ethiopian and Somalian Plateaux this does not rest at the original elevation of the Arabo-Ethiopian Swell in that region, and its lavas might better be considered with the extensive flood fissure lavas of internal Afar. Problematic occurrences of small isolated patches of basalts, most probably of Aden Series age, are found in Ogaden, and north of Mogadisho in Somalia.

It is difficult to estimate the quantitative occurrence of the Aden Series lavas owing to the isolation of the numerous centres involved; thicknesses are much too variable for a significant figure to be quoted. Neglecting pyroclasts, which are inextricably intermixed with the Pleistocene lacustrine sediments, the area covered by the Aden Series lavas on the Rift floor totals about 50,000 sq.km, together with about 15,000 sq.km of basalt on the Ethiopian Plateau. These lavas can be measured in terms of tens of metres compared with the hundreds or even thousands of metres for the Trap Series. To a first approximation the volume ratio of the Trap Series lavas to the Aden Series lavas is of the order of 500:1.

Dating of the Aden Series lavas by means of the interbedded fossiliferous Pleistocene lacustrine sediments is a promising field for the future, and particularly in northern Afar which suffered a marine incursion during the late-Pliocene. The eruptions of Alid have been studied in this way and the volcano has been proved to have had a submarine origin (Dainelli 1943). It is also hoped to make absolute age-determinations on Aden Series rocks in the near future.

Dainelli has claimed to recognise two alignments of Aden Series volcanic centres in Afar, radiating respectively N.N.E. and E.N.E. from the vicinity of Fant-ale, but any significance of these must be regarded in the light of the different petrological suites and different ages thus brought into association. However, there is evidence (Gouin 1963) that the first-mentioned alignment coincides with a major seismic line in Ethiopia and with a northwards extension of the Wonji fault-belt; the second line closely follows the original fault-line which separated the Somalian Plateau from Afar.

The most recent fissure basalts of the Rift floor have been extruded from lines which are easily recognisable: these include the fissure-faults of the Gariboldi Pass region, situated upon the Wonji fault-belt (author 1962b), and the extensive fault (?) - fissures of west-central Afar trending N-S to N.N.W.

-S.S.E. from which wide sheets of scoriaceous basalts have flooded northeastwards over a monotonous plain of fluviatile and lacustrine sediments towards Egoji Bad (Lake Julietti). The N.N.W.-S.S.E. alignment of the Erta-ale volcanic chain, active at the present day, suggests an underlying fissure-tectonic system paralleling the Gulf of Zula and Salt Plain graben. Fissure-faults in the hinterland west of Assab on the Danakil Horst have provided both flood basalts and end-phase cinder cones.

Quaternary silicic eruptions are restricted, to the author's knowledge, to the volcanic centres of Chubbi, Fant-ale, Dofane, Amoissa and Dubbi. In the case of Chubbi thick obsidian lavas have been extruded very recently in the site of unique transverse faulting of the floor of the Main Ethiopian Rift.

Quasi-intrusive masses of hyperalkaline undersaturated lavas of late Tertiary age, as well as fragments of such rocks associated with the ejecta of Quaternary explosion craters (author 1961) pose special petrogenetic problems which will be briefly mentioned below. The presence of carbonated dykes or associated carbonated hot-springs suggests the action of carbonatitic magma. Trona-bearing lavas form the characteristic 'blisters' of the plain south of Fant-ale but their geochemistry has not yet been studied.

Summarising the discussion thus far: the Trap Series can be considered as the immense mass of flood basalts and other lavas capping the Ethiopian and Somalian Plateaux, except where overlain by the rare patches of evidently recent basalts, and underlying the Aden Series lavas and Pleistocene sediments of the Rift System floor. Assuming a single magmatic phase for the Cainozoic in the Horn of Africa and the Yemen, by far the greater quantitative activity took place before the formation of the Rift System. Both for the Trap Series and the Aden Series the alignment of fissures and centres is tectonically controlled to a very marked degree, that is directly or indirectly to the meridional Rift faulting cutting the Arabo-Ethiopian Swell.

2. Petrographical

Only a brief summary of the petrography of the Ethiopian lavas, based on the work of previous authors, will be given here. In most cases these earlier petrographic descriptions are barely adequate, the compositions of the feldspars and pyroxenes rarely being determined (notable exceptions are the works of P. Comucci and O. Hieke Merlin).

(a) The Trap Series

The Ashangi-type basalts have a remarkably uniform petrography. They are typically dark-coloured, very fine-grained holocrystalline rocks composed

Oligocene age in northern Ethiopia. This Oligocene age is based by Dainelli on the evidence of cumulative suggestions, in relation to the magnitude of the unconformity between the Trap Series and the Lower Cretaceous marine sediments in eastern Arussi, in the closely contemporaneous relation between the first flood basalt eruptions and the preceding Upper Eocene uplift of the Arabo-Ethiopian Swell, in relation to the Miocene faulting which cuts all the lavas of the Trap Series except perhaps the last of the Magdala flows, in relation to the denudational chronology and to the contained fauna and flora. The great shield volcanoes may have terminated their activity in the Miocene, whilst the hyperalkaline-undersaturated centres of Adua-Axum, Senafe, Wachacha-Yerer, Chilalo, Karsa, etc., possibly the surface manifestations of underlying carbonatitic bodies, are of end-Trappean age and possibly contemporaneous with the major rift faulting; of probable similar age (Late Miocene) are numerous domes and plugs of coarse alkaline trachytes which are particularly common on the Ethiopian Plateau in the regions of Lake Tana and in central Wollega and northern Jimma.

It may be mentioned that the author is at present engaged on potassium-argon dating of Trap Series lavas, and preliminary results will have been published by the time this paper is in print.

In summary, the Oligocene-early Miocene Trap Series lavas essentially pre-date the rift faulting and so are found to have been displaced between the covering rocks of the Plateaux and the flooring rocks of the Rift, remaining almost everywhere in their original sub-horizontal condition.

(b) The Aden Series

The lavas of the Aden Series are distinguished in the field from the Trap Series by their evident post-rifting age and by their local and thin development. The Aden lavas tend to be largely restricted to the region of the Rift floor, and particularly where this floor is broken by Quaternary faulting (author 1960). However, this morphological distinction is not fundamental, for a number of localities are known on the Ethiopian Plateau where manifestly fresh basalts have flowed down the sides of river gorges formed of dissected Trappean stratoids, and derived from well-preserved cones often in association with explosion craters. These recent lavas on the Plateau, as in the Rift, are never very extensive by Trappean standards and the fact that they can be so distinguished from the Trap Series flows indicates that the division of the Cainozoic volcanics of Ethiopia into two Series is not altogether an arbitrary one, even though chemical data to be presented below indicate their magmatic unity.

Dainelli (1943) reviews the evidence that the Aden Series is of Lower Pliocene-Recent age, though it has yet to be proven that there was a significant hiatus in volcanic activity between the last of the Trappean central eruptions and the earliest of the Aden central eruptions; however, besides being peculiarly restricted to the Rift floor these early Aden lavas show a further stage of chemical evolution upon the Magdala silicics (see below). The most immediately striking lavas of the Aden Series are the extremely recent scoriaceous flood basalts, mostly extruded within the last 1000 years, and these enable a division to be made within this Series also:

2. Holocene phase of highly scoriaceous flood basalts extruded from fissures, linear faults, ring faults, cauldron margins, etc.; these lavas occur both on the Plateaux and in the Rift. Rare silicic centres active during this period include Dubbi, Dofane, Fantale and Chubbi.

1. Pliocene-Pleistocene phase of hyperalkaline silicic central lavas entirely restricted to the Rift floor; associated tuffs are thickly and extensively developed. Basalts are very subordinate in this phase and are chiefly of central type.

Gortani & Bianchi (1941) have claimed to recognise an earlier basaltic phase preceding the Pliocene silicics, and have also separated the Pliocene from the Quaternary silicics. But their earlier basaltic phase can be generally identified with the Trappean flood basalts of Afar, whilst no evidence is put forward for a criterion in distinguishing Pliocene from Quaternary silicic lavas: in fact chemical data confirm field evidence in showing that there has been a single extended phase of silicic igneous activity during the late Cainozoic in the Ethiopian Rift. On the other hand, evidence will be presented below to suggest that the very latest flood basalts do belong to a separate phase, chemically speaking, from the bulk of the Aden Series basalts.

The two recognised phases of eruption within the Aden Series listed above seem to be quite unrelated from the genetic view point, both in spatial distribution and in temporal concentration. If the earlier phase of silicics has been derived from fractionation within a parent basaltic magma (as chemical evidence suggests) the physical separation of the fractionates from any remnant basalts has been remarkably effective, in complete contrast with the silicics of the Magdala Group which are generally intimately and often gradationally associated with basalts and accumulates. This fact, allied to the smaller quantitative development of the Aden Series lavas, suggests not merely that supply of magma was more limited but that its ascent to the surface has been more severely inhibited.

The second, basaltic episode of the Aden Series, possibly usnering in a new magmatic phase, is frequently found to have been peculiarly associated with the

essentially of feldspar and pyroxene. Frequently the texture is so fine-grained that determination of mineral composition from optical properties is rendered almost impossible; glassy texture is not known.

Generally the feldspar is a plagioclase of composition 60% An, that is labradorite, but more calcic examples are not uncommon up to labradorite--bytownite. Where determination of composition at points across a crystal are possible a slight decrease in An content is sometimes found from the nucleus to the periphery, but this phenomenon is not general and in most cases there is evidence of a single period of very rapid chilling and crystallisation of the lava. The pyroxene is augite with tendencies to titanaugite such as is characteristic of alkaline lavas. Where larger crystals of pyroxene are developed they are notably less titaniferous than those within the groundmass; commonly they are slightly zoned with an increasing titanium content from the nucleusto the periphery. Olivine is not common in the Ashangi-type basalts and where present it usually occurs in the form of phenocrysts with pyroxene; in this form it tends to be rather iron-rich, a hyalosiderite, with frequent alteration to iddingsite. Iron oxides and especially magnetite are generally abundant accessories in the Ashangi-type basalts, though not so abundant as in the Magdala basalts.

The mineralogy of the Ashangi basalts is therefore consistent with that of alkaline basalts deficient in olivine, and this essential nature is confirmed by the observation of occasional peridotitic nodules within these lavas.

The Magdala-type basalts have a much more variable petrography than the Ashangi-type basalts, due to the results of fractionation, contamination and accumulation. All variations are known through augitites, limburgites, hornblendites, kenyites, micro-gabbros and quartz basalts, as well as biotite-bearing basalts, and olivine trachybasalts. The Magdala-type basalts are very commonly porphyritic and the phenocrysts may be plagioclase, pyroxene and/or olivine. The olivine when present occurs as large zoned crystals, a typical example having a composition of 15 Fa at the nucleus and 30 Fa at the periphery; these olivine crystals are frequently badly corroded and rounded due to primary reaction with the residual liquid, and serpentinisation is common as a secondary (?) alteration. The pyroxene is titanaugite, though diopsidic augite occurs as phenocrysts in some of the more femic rocks; Magdala-type basalts are recorded with a magnesium-rich pyroxene of the clinoenstatite or pigeonite type, in these cases an ophitic texture usually being developed. Hypersthene has also been recorded, from basalts north of Ankober for example. Although the occasional presence of these pyroxenes indicates that tholeiitic tendencies occurred in the Magdala lavas, the overall alkaline nature of the Group is further confirmed by chemical studies (see below).

The plagioclase phenocrysts in the Magdala basalts are generally large and may be up to 5cms. in length in the coarse rhomb-porphyries; the presence of a great abundance of these phenocrysts sub-aligned parallel to the flow direction gives rise to a characteristic platy texture, often accompanied by numerous vesicles and amygdales. The plagioclase phenocrysts are typically labradorite, an example of the common zoning being 70 An at the nucleus to 55 An at the periphery, though in the more sodic flows a peripheral value of 35 An may exceptionally be reached. The plagioclase laths of the groundmass are typically labradorite-andesine; they usually show only Carlsbad twinning, in contrast with the phenocrysts where albite twinning may also be present. Interstitial alkali feldspar is suspected in some specimens. Iron-ore minerals may be very abundant in some Magdala basalts though rather rare in others, and magnetite dominates over ilmenite. Apatite may occasionally be almost an essential mineral.

Amygdaloidal flows are common amongst the central-type basalts of the Magdala Group, the amygdales being formed of such minerals as agate, chalcedony, zeolites and semi-opal. This, together with the occurrence of hydrous accumulates, suggests that the magma supplying the Magdala lavas was relatively enriched in volatiles. Accumulates such as picrites, augitites and limburgites are known from a number of localities on the Ethiopian Plateau; hornblendites and hornblende-biotite basalts are rare but of petrogenetic interest.

The alkaline nature of the Magdala basalts is emphasised by the mineralogy and chemistry of the more-silicic derivatives whose presence largely defines the Magdala Group. These range from olivine trachytes through phonolites and trachyliparites to comendites and pantellerites; obsidians are common. The great variety of these lavas (according to the degree of differentiation - see below) makes a general description of their mineralogy difficult.

Very generally, in the intermediate lavas (%SiO_2 between about 55 and 65) sodic plagioclase, typically andesine, is developed together with occasional alkali feldspar; slightly sodic augite and common magnetite occur in the groundmass with plagioclase, but not infrequently in these lavas the groundmass is a devitrified glass. Rarely olivine is present, as in the Entotto lavas, as iron-rich (88Fa) phenocrysts surrounded by aegirine-augite or arfvedsonite.

The mineralogy of the hypersilicic lavas varies according to the Na/K and Ca/Na+K ratios. Sanidine and/or anorthoclase are typically present in relatively large phenocrysts, and in the less silicic varieties some oligoclase-andesine may accompany the alkali feldspar in the groundmass. Quartz forms shapeless granules in the groundmass but sometimes also forms subhedral phenocrysts. Common pyroxene is aegirine-augite, but aegirine and cossyrite are also known; amphiboles such as brown hornblende, arfvedsonite or barkevikite are sometimes present, and riebeckite in the hyperalkaline lavas. Magnetite, haematite, zircon and apatite are the typical accessories; calcite is also known.

The groundmass of these more-silicic Magdala lavas is frequently glassy, and may show strongly developed flow-structures as well as spherulites, schlieren and lava xenoliths, the last showing varying stages of ingestion until hybrid lavas are obtained; the spherulites are typically of an orthoclase-chalcedonic constitution. Occasionally the whole rock is a microcrystalline or cryptocrystalline quartzo-feldspathic mass, tending in some specimens to an alkaline obsidian. First generation crystals in the silicic lavas may show evidence of reaction, as mentioned above with olivine; anorthoclase crystals may similarly occur corroded not only round the outer rim but also within the borders of occluded gases and liquids, a second generation anorthoclase being formed in intimate association with glass; quartz may also suffer corrosion. The phenomenon of secondary accretion of anorthoclase upon orthoclase has been reported by Hieke Merlin (1953).

The great variety of texture and mineralogy within the Magdala-type silicics, according both to complex association of fractionation, contamination and hybrid processes and to the particular physical conditions of magma storage and extrusion, is such that a classification of these lavas is best made according to their chemistry. This topic is discussed below.

Though quantitatively minor the undersaturated hyperalkaline lavas are of especial interest to the petrologist because of their close association with the Rift tectonics, and because they seem to have derived from a carbonatitic magma off the line of the alkaline basalts and the alkaline basalt derivatives. These undersaturated lavas and intrusives, of end-Trappean to Recent age, form domes, plugs, bosses and dyke-sheets which are characterised by such minerals as sanidine or anorthoclase with nepheline or rarely leucite, as well as analcime, nosean, sodalite, riebeckite, cossyrite, kaliophilite, biotite, etc.. Calcite is sometimes an essential mineral in these rocks.

(b) The Aden Series

The silicic lavas of the Aden Series show the same great variety of structure, texture and petrography as those of the Trap Series. However as mentioned previously, the Aden Series silicics are rarely found intercalated with any associated basalts in contrast with the Magdala Group silicics. Perhaps for this reason intermediate lavas are rarely represented amongst the Aden lavas, the first phase of the Series to appear being represented by vitrose or vitrophyric highly-alkaline liparites, pantellerites and comendites. According to Gortani & Bianchi (1941) these lavas have typically risen up centres situated at the intersections of cross-faulting, and this has been noted by the author in the case of the active liparitic-obsidian volcano of Chubbi but not evidently in the site of the large pantelleritic centre of Fantale.

The mineralogy of the Aden silicics is variable enough to make a generalised statement have little significance. However, a typical association is one of sanidine and/or anorthoclase phenocrysts in a glassy groundmass with marked flow-structures and abundant spherulites. Quartz is less common as phenocrysts, which may also rarely be formed of zoned aegirine-augite, barkevikite or cossyrite, and all of these minerals may form microlites in the groundmass, together with arfvedsonite and riebeckite. A porphyritic liparite from Badda-Samoti is noted for tridymite-bearing cavities, and from close to this locality De Angelis (1925) has described dancalite which is a lava composed of large phenocrysts of albite-oligoclase and smaller crystals of green augite or rare brown hornblende set in a groundmass of sodic plagioclase, analcime and microlites of aegerine-augite; this intermediate lava is essentially a hyperalkaline trachyandesite. Rare alkaline trachytes in the Aden Series are characterised by oligoclase-andesine, diopsidic augite, and less common alkali feldspar and sodic pyroxene. Undersaturated silicics are known in association with the explosion craters of the Rift (author 1961) and from the Lake Tana basin (Comucci 1950). Trona-bearing lavas are associated with the Wonji fault belt near Metahara and there is no doubt that these, together with the more normal undersaturated lavas, have been derived from magmas with carbonatitic associations.

It is here tentatively proposed that the available petrographic evidence suggests a more melanocratic character for the silicic lavas of those Aden centres which are situated upon the Wonji fault belt than for those away from it. This melanocratic character is strongly emphasised in the pantelleritic lavas of Fantale, and to a lesser extent in similar lavas from Ajelu, Adama, and various centres in southern Afar and French Somaliland; it is also present in the silicic lavas of the Jimma region (Pagliani 1940) where strong meridional faulting is developed immediately to the north.

The basalts of the Aden Series, chiefly of late Quaternary age, are mostly characterised by their extremely scoriaceous aspect, though amygdaloidal flows are almost unknown. Olivine is usually present and often abundantly so, with two generations frequently developed; iron-rich forms with a composition of 30-40 Fa are usual with common alteration to iddingsite. Augitic pyroxene commonly accompanies the olivine as phenocrysts; titaniferous or sodic pyroxene is less typical of the Aden basalts than the Trap basalts. Plagioclase is rare as phenocrysts and where present is generally rather calcic, 75-85 An with the usual zoning of a more calcic nucleus and less calcic periphery. The second generation plagioclase of the groundmass is typically labradorite or labradorite-bytownite. Accessory minerals include important magnetite, ilmenite, apatite and even occasionally haematite.

Very frequently the recent basalts of the Aden Series have a glassy groundmass, and occasionally as in the Gariboldi Pass region tachylites are found. These examples of partial crystallisation in the Aden basalts are evidence of possible tholeiitic tendencies, in addition to which is the lack of highly undersaturated basalts of this age. However, the presence of more aluminous and

mafic, less femic basalts along lines of intense faulting is suspected, though present evidence for this remains inadequate. There is no obvious distinction between the petrography of the Aden basalts of the Rift and of the Plateaux.

3. Chemical

Although numerous analyses of isolated lava specimens from Ethiopia have been made by various Italian authors the Cainozoic lavas of this region are of such extent and, in their fractionates, of such variety, that their chemistry is still not well known. It is hoped to remedy this situation somewhat in projected work at the University College of Addis Ababa, but for the present paper the compendium of analyses listed by Dainelli (1943) must be used, supplemented by the analyses published since that date and in particular those made by P. Comucci and O. Hieke Merlin. The author regrets that the data of Pagliani (1940) have not been obtainable for incorporation in the present paper.

It has not proved an easy task to allocate the analysed lavas to their respective Series or Group for the purposes of the comparisons made below. Indeed, many of the excellent analyses of Comucci (1950) for the Lake Tana region volcanics have had to be discarded owing to the impossibility of precise location of the specimens concerned, and hence the identity of their parent formations. In most cases the distinction between the Trap Series and the Aden Series lavas as given in the analytical tables of Dainelli and others has been fairly simple to make, especially as Dainelli has already recognised these two Series as separate chemical entities; however, a few juxtapositions have been made according to the light of more recent researches. The distinction between Ashangi and Magdala Group basalts has proved much more troublesome to make, and has been based partly on the work of Gortani & Bianchi (1941) and Dainelli (1943) but chiefly according to the author's personal knowledge of the region concerned. A detailed understanding of the field-relations between the Ashangi and Magdala Group basalts is one of the outstanding problems of Ethiopian vulcanology.

The utility of the chemical data presented below is limited according to the relative fewness of the accepted analyses. From the statistical aspect an order of ten times as many analyses would be desirable to examine the trends discussed below, together with a precise identification of the Series or Group to which each analysed specimen belonged; ideally, each analysis should be accompanied by an absolute age-determination. In the present paper there is the possibility of excessive weight being given to any chemical peculiarities for a well-sampled region, for example the volcano Fant-ale in forming the average composition of the Aden Series hypersilicic lavas. The substantiation or otherwise of any regional chemical variations in the Ethiopian volcanic province can only be made in the basis of many more data.

The boundary distinctions between basalts and intermediate lavas and between intermediate and hypersilicic lavas has been made chiefly on the basis of petrography, but with some weight being given to SiO_2 content where the rock is glassy or where the petrography is ill-described. A few instances are known where the rock-type assignation would seem to need revision according to more modern nomenclature; the author has let stand the assigned names given by the previous workers concerned in the absence of being able to examine the specimens himself.

For the above reasons, therefore, and taking into account the standard deviations obtained in making the listed averages (never better than $\pm$ 5%), no undue consideration can be given to differences of less than the order of 5 per cent of the actual by weight for any given element. Such small differences are listed as 'zero' when making comparisons, though further research may reveal them as significant in some instances. It will be seen that in the tables of comparative chemical data given later the values of SiO_2 are virtually identical for a given compositional family; only in the case of the intermediate lavas has this been deliberately obtained, for the Aden intermediates where analyses are very few. Otherwise the similar SiO_2 values indicate the success in distinguishing lavas types for 'boundary cases'. (It may be noted that any changes of SiO_2 content during chemical evolution within the compositional families of Ethiopian lavas will prove more difficult to detect on this account, and also because of the relatively small increment of any such changes compared with those for the other major elements.) The similar SiO_2 values greatly facilitate chemical comparisons for the other elements.

In all cases the chemical averages given in this paper have been re-calculated in terms of 100.0 per cent unless otherwise stated.

(a) The alkaline nature of the Ethiopian lavas

The reader is presumed to be already acquainted with the generally recognised chemical and petrographic differences between tholeiitic and alkaline basalts, as expressed particularly by Kennedy (1933), Tilley (1960), Turner & Verhoogen (1960, chapter 8) and Yoder & Tilley (1962).

The alkaline nature of the Ethiopian basalts and their fractionates as expressed in their petrography has already been shown, but a summary from Yoder & Tilley can be cited here as confirmation before continuing with the intimately related chemical discussion:

> Tholeiitic basalts consist essentially of augite (strongly zoned and often sub-calcic), plagioclase (near An50) and iron oxides. Olivine is subordinate or absent. A vitreous silicic residuum is common, sometimes crystallised to a quartzo-feldspathic intergrowth. More than one pyroxene is commonly present, pigeonite and/or hypersthene

> accompanying the augite. Alkaline basalts are marked essentially by the presence of a calcic or titaniferous augite, often with sodic tendencies. No other pyroxene is present, but olivine may be abundant both as phenocrysts and in the groundmass. No glass occurs. Sanidine is occasionally present.

Chemically the distinctions between the two types of basalts are less clear cut, as would be expected from their petrogeneses according to the researches of Yoder & Tilley (1962). Very generally speaking alkaline basalts are poorer in SiO_2 than tholeiites and they contain more than 3 per cent alkalis; the alkaline basalts are also marked by tendencies to higher ferric/ferrous iron and Mg/Ca ratios than the tholeiitic basalts though no sharp dividing lines can be drawn. Yoder & Tilley have classified the basalts according to their chemical norms, and this will be noted in relation to the Ethiopian basalts later. For the present the data given in Table 1 are cited as strong evidence of the alkaline nature of the basalts of the Ethiopian province.

It is immediately evident that the Ethiopian basalt average shows a close resemblance to the world-average alkaline basalt (Nockolds 1954), and in some features, for example the rather low MgO content, to the olivine-deficient alkaline basalts. The high Na/Si and ferric/ferrous iron ratios in the Ethiopian basalts are typical of the alkaline type, by contrast with such continental flood lavas of the tholeiitic type as form the Deccan traps and the Columbia River basalts.

TABLE I

Average compositions of some world alkaline basalt associations

	1.	2.	3.	4.	5.	6.	7.
SiO_2	46.8	45.8	46.8	47.7	47.1	44.7	44.7
TiO_2	2.2	2.6	3.0	3.2	2.9	2.9	2.0
Al_2O_3	14.6	14.6	14.6	15.2	15.8	17.4	15.7
Fe_2O_3	5.7	3.2	3.7	2.3	4.0	2.8	4.1
FeO	7.3	8.7	7.9	8.7	8.3	9.4	8.5
MnO	0.2	0.2	0.2	-	0.2	0.1	0.1
MgO	6.6	9.4	6.8	9.7	7.4	6.6	8.4
CaO	10.3	10.7	12.4	8.9	9.4	10.8	11.6
Na_2O	2.6	2.6	2.6	2.7	3.1	2.7	2.9
K_2O	1.4	1.0	1.1	1.6	1.3	1.0	1.2
P_2O_5	0.4	0.8	0.5	-	0.5	0.5	0.8
H_2O	1.9	0.4	0.4	-	-	1.1	-

1. Average composition of 64 Ethiopian basalts (of all ages) - see Appendix 1.
2. " 96 alkaline basalts (Nockolds 1954)
3. " 22 olivine-deficient basalts of alkaline type (Nockolds 1954)
4. " 2 Gough Island olivine basalts (LeMaitre 1962)
5. " 27 Carboniferous Scottish olivine basalts (Tomkieff, cited in Turner & Verhoogen 1960, table 14)
6. " 4 Kenyan alkali basalts (from Campbell Smith 1931)
7. " 11 Rungwe basalts (Harkin 1960)

TABLE 2

Average composition of some world alkaline intermediate lavas

	1.	2.	3.	4.	5.
SiO_2	58.9	61.9	60.1	61.2	60.2
TiO_2	0.7	0.6	0.6	0.7	0.4
Al_2O_3	16.8	16.9	16.5	19.0	17.7
Fe_2O_3	3.8	2.3	3.8	2.7	2.5
FeO	2.9	2.6	3.1	1.4	2.9
MnO	0.2	0.1	0.2	0.1	0.2
MgO	0.9	1.0	0.5	0.6	0.2
CaO	2.5	2.5	1.7	1.2	1.9
Na_2O	6.1	5.5	6.6	6.8	7.5
K_2O	4.7	5.9	4.9	6.1	4.9
P_2O_5	0.2	0.2	0.1	0.2	0.4
H_2O	2.3	0.5	1.9	-	1.2

1. Average composition of 33 Ethiopian intermediate lavas (see appendix 1.)
2. " 25 alkaline trachytes (Nockolds 1954)
3. " 6 Kenyan phonolites (from Campbell Smith 1931)
4. " 5 Rungwe phonolitic trachytes (Harkin 1960)
5. " 5 Saint Helena Island phonolites (Daly 1927)

TABLE 3

Average composition of some world alkaline hypersilicic lavas

	1.	2.	3.	4.	5.
SiO_2	71.0	72.3	73.3	70.2	67.4
TiO_2	0.4	0.4	0.3	0.3	0.6
Al_2O_3	11.7	10.9	11.6	13.5	16.9
Fe_2O_3	2.7	2.9	1.7	1.9	2.1
FeO	2.1	2.4	2.4	3.1	0.9
MnO	0.1	0.1	nil	-	0.1
MgO	0.3	0.2	0.2	0.1	0.2
CaO	0.9	0.7	0.8	0.6	0.3
Na_2O	5.0	5.2	4.8	5.4	5.8
K_2O	4.5	4.4	4.0	4.9	5.5
P_2O_5	0.1	0.5	nil	-	0.2
H_2O	1.2	nil	0.7	-	-

1. Average composition of 50 Ethiopian hypersilicic lavas (see appendix 1.)
2. " 39 perlkaline rhyolites (Nockolds 1954)
3. " 1 comendite from Njorowa Gorge, Kenya (Campbell Smith 1931)
4. " 3 Bouvet Island late differentiates (Broch, in Le Maitre 1962)
5. " 2 Rungwe quartz-trachytes (Harkin 1960)

Individual features of the Ethiopian basalts include their low average MgO content such as is characteristic of the olivine-deficient alkaline types, and this particularly marked for the Ashangi basalts (6.65% MgO) whose petrography reveals a general lack of modal olivine. The frequent presence of magnesian olivine in the Magdala basalts and especially in the derived accumulates is reflected in the higher MgO (7.4%). In the Aden basalts the average MgO is very low (5.95%), but a high iron content allows the presence of the modal iron-rich olivine observed in many specimens; however, the tendency towards a more tholeiitic character in the Aden basalts will be more critically examined below.

Other individual traits of the Ethiopian basalts manifested within the framework of their indisputably alkaline nature are their high ferric/ferrous iron and H_2O averages, plus tendencies to rather low Ti and high K. In particular the high ferric iron content is marked, and is observed show an inverse relationship to Al during the evolution of the Ethiopian basalts (see later). It must be emphasised that these individual chemical features of the Ethiopian basalts are of as much significance, and probably no more, than the individual features of the chemistry of any other world alkaline province; that is to say, any differences in this respect are due to local, accidental conditions within the region of magma formation in the upper Mantle and not to any fundamentally singular conditions of petrogenesis. However, it is notable that in the Ethiopian basalts a high degree of oxidation coincides with a relatively high degree of hydration, though these two factors do not show sympathetic variation during the temporal evolution of this basaltic province.

Compared with the average of four Kenyan basalts the average Ethiopian basalt shows remarkably few significant differences apart from a higher saturation with respect to Si/Al. Although the tectonic environment is common to both, yet the development of the Kenya basalts is very restricted quantitatively, spatially and temporally compared with the Ethiopian basalts. The Rungwe basalts of Tanganyika have a ferric/ferrous iron ratio almost as high as in the Ethiopian basalts, but Mg/Ca is much higher than in the Rift basalts to the north, according more with the average world alkaline basalt in this respect. A full examination of the literature shows that the basalts of the African Rift System tend to be poorer in alkalis than are the basalts of the oceanic ridges, especially for the volcanoes situated along the mid-Atlantic ridge (see Daly 1927, LeMaitre 1962).

A study of the more-silicic lavas of the Ethiopian province confirms the alkaline nature of the parent basaltic magma from which they were derived. Tables 2. and 3. compare the compositions of the average Ethiopian intermediate and hypersilicic lava respectively with lavas of similar chemistry from other parts of the world. The close chemical resemblances are evident and point to the same mechanisms operating during magmatic crystallisation.

Within this framework of similarity the Ethiopian intermediate lavas again manifest a rather high ferric/ferrous iron ratio, though this is matched by the intermediate lavas of Kenya which have originated in the same tectonic environment (note: the bulk of the Cainozoic lavas of Kenya are of intermediate composition; they are mostly highly alkaline but some are known which are highly saturated and calc-alkaline). The Ethiopian intermediate lavas also follow the basalts in being relatively highly hydrated, and again this is almost matched by the Kenyan intermediate lavas; these two factors of greater oxidation and higher hydration seem to mark the African Rift System lavas compared with the alkaline lavas of other world provinces.

The Ethiopian hypersilicic lavas show high oxidation and hydration; they show a closer affinity to the peralkaline rather than the merely alkaline world averages of Nockolds (1954). Comparisons with the provinces to the south are uncertain owing to the paucity of data from those regions, and also because hypersilicic lavas are subject to particular, local conditions during fractionation which can markedly affect their ultimate composition. However, oxidation and hydration are once again probably higher for the African Rift hypersilicics, and the confirmation (or disproof) of this generalisation is important in view of the possible petrogenetic implications concerning the condition of the upper Mantle beneath the Arabo-Ethiopian and East African Swells.

(b) The evidence for differentiation

The intimate field association of lavas of various gradations of chemical composition, particularly within the Magdala Group, is so evident as to have led almost all geologists working in Ethiopia to presume differentiation processes to account for this association. The best chemical evidence to date for such processes is given by Hieke Merlin (1953), though without full interpretation. But until the advent of a detailed petrological study of a single Ethiopian volcanic centre - on the lines of LeMaitre (1962) for Gough Island - nothing is justified from the study of available analyses of the numerous isolated specimens except to draw conclusions which are at once generalised and provisional. On the other hand, the ubiquitous occurrence of lavas in Ethiopia with the characteristic petrography and chemistry of differentiates derived from primary alkaline basaltic magma should lead the petrologist acquainted with other world alkaline provinces to expect fractionation processes to have operated in the Ethiopian lavas also.

The data presented in Table 4. are strongly suggestive of differentiation having been the primary process in the formation of the Ethiopian silicic lavas, both for the Magdala and the Aden assemblages. In each of these two series the following chemical trends are manifested with increasing SiO_2 :

-decreasing Ti, ferric and ferrous iron, Mg and Ca

-increasing ferric/ferrous iron ratio, whilst Al and Na increase to the intermediates and then decrease; a similar behaviour is shown by K though

with a tendency to a continued increase throughout the whole fractionation process. In the norms these changes are reflected increasing quartz, an increasingly sodic composition of the plagioclase, and decreasing proportions of femic and iron-oxide constituents.

All these changes are exactly paralleled by the alkaline differentiation series of the Gough Island lavas (LeMaitre 1962), though for this particular series differentiation only proceeded to lavas with SiO_2 content up to about 61.5 per cent. This similarity to a well-attested example, allied to the petrographic evidence for a continuous series within the Magdala Group lavas of many of the shield centres from normal alkaline basalt to comendite and pantellerite, during which olivine becomes progressively more iron-rich and plagioclase more sodic, can leave little doubt of the operation of differentiation to produce this series. (note: the SiO_2 histogram of 160 Ethiopian lavas shows peaks at 47% and 72% with a minor peak at 64%; there is a trough at 53% indicating rapid fractionation through this composition without opportunity for magmatic tapping.) The same chemical trends are manifested for the Aden lavas, though in the field lavas of different composition show little of the intimacy of the Magdala lavas, and furthermore Aden lavas of intermediate composition are distinctly uncommon. Whilst there can be little doubt that differentiation processes account for the silicic lavas of the Aden Series, their separation from the parent material and the paucity of intermediate representatives suggests a greater difficulty of ascent than for the Trap Series lavas. It has been noted by the author that the latest basalts of the Aden Series have ascended up fissures closely situated to earlier silicic centres, for example the basalts of Sabober in relation to the dormant silicic centre of Fant-ale (author 1962b).

The hyperalkaline silicic lavas, for example those of Adua-Axum and Senafe, fit fairly well into this differentiation series but their less silicic equivalents, such as the basanites and nepheline tinguaites of the Arussi Highlands. show a degree of undersaturation and an enrichment in alkalis which is incompatible with derivation from a basaltic magma; for example, a nepheline tinguaite from Dodola, Arussi, contains 47.43% SiO_2 , 16.83% Al_2O_3, 7.11% Na_2O and 3.00% K_2O, whilst a similar rock from Mt. Lajo, Arussi, contains 50.69% SiO_2, 20.18% Al_2O_3 , 9.34% Na_2O and 4.77% K_2O (both analyses in Repossi 1932). It is of interest that these two specimens may have been collected from the dyke-like intrusions which form the Badda-Kakka ridge and parallel the Rift System to the west. Normatively these two rocks are extremely rich in feldspar, and a possible clue to their petrogenesis may lie in this fact.

Yoder & Tilley (1962) consider, contrary to the view of Kuno (1960), that high-alumina basalt can be derived from a melt of eclogitic composition in the upper Mantle merely by a slight change in the physico-chemical conditions which normally give rise to either tholeiitic material (by removal of omphacite at the expense of garnet) or alkaline basaltic material (by increase in omphacite) at low pressures. A source rock of separate chemical composition is not required to explain the formation of the high-alumina basalts, but merely a mechanism for the enrichment of plagioclase; such a mechanism has previously been suggested in the form of melting of earlier plagioclase accumulates, but Yoder & Tilley present evidence to show that such an enrichment can be caused by a high water vapour pressure which delays the crystallisation of plagioclase within either tholeiitic or alkaline basaltic magmas. However, Waters (1962) presents strong field-evidence for a separate source for the high-alumina basalts of the Columbia River tholeiites, where these rocks and their fractionates were being erupted continuously during the period of formation of the normal tholeiites.

TABLE 4

The chemistry of the Ethiopian basalts in relation to that of their fractionates

	1M	2M	3M	1A	2A	3A
SiO_2	48.4	60.5	72.1	48.3	60.3	71.9
TiO_2	2.4	0.6	0.45	2.05	0.9	0.4
Al_2O_3	15.5	17.6	12.9	14.4	16.2	11.0
Fe_2O_3	6.2	3.9	2.4	6.85	4.45	3.0
FeO	6.5	2.8	1.8	7.45	3.7	2.4
MgO	6.2	0.8	0.3	6.0	1.1	0.3
CaO	9.8	2.2	0.7	11.1	3.75	1.0
Na_2O	3.0	6.5	4.9	2.55	6.0	5.4
K_2O	2.0	5.1	4.5	1.3	3.6	4.6
Norm:						
Qtz	-	-	27.6	0.7	4.8	27.4
Or	10.8	29.6	25.2	7.5	20.3	25.4
Ab	25.6	53.6	41.2	21.5	51.8	31.3
An	22.0	4.2	-	22.6	6.9	-
Ne	-	1.1	-	-	-	-
Ac	-	-	-	-	-	7.1
Ns	-	-	-	-	-	0.9
Di	22.3	5.8	2.9	27.1	9.5	4.2
Ol	7.0	-	-	-	-	-
Hy	3.1	1.4	0.3	11.6	1.5	3.0
Ilm	4.1	1.1	0.8	3.3	1.5	0.7
Mt	5.1	3.2	2.0	5.6	3.7	-

1M. Average chemical and normative composition of 17 Magdala basalts (see Appen. 1.)
2M. " 26 Magdala intermediates
3M. " 24 Magdala hypersilicics
1A. " 25 Aden basalts
2A. " 7 Aden intermediates
3A. " 26 Aden hypersilicics

The occurrence of high-alumina basalts and high-alumina fractionates (note: the

latter were not necessarily derived from the former) in Ethiopia is well-established, indeed. Of the specimens listed in Appendix 1. thirty-three can be considered to belong to this category not including the hyperalkaline rocks. High-alumina basalts and high-alumina fractionates occur at all levels in the stratoidal column in Ethiopia, but there seems to be a tendency to a spatial concentration in regions of intense faulting, a property already noted by Waters (1962) for the Columbia River high-alumina tholeiites. Thus the regions of high-alumina lavas in Ethiopia can be summarised as follows:

- the Aden basalts and intermediates of Enjabara, Gojjam;
- the basalts of the Entotto arc above Addis Ababa;
- the Trappean lavas of Debra Berhan, Debra Sina, and the Lake Haik region;
- the silicics of the dormant volcanoes of Alid and Dubbi in northern Afar, and of Ajelu, Iddidlei, and the Guma graben (Trappean?) in central Afar;
- the most recent basalts of the Wonji fault belt, for example at Walenkiti, Ajelu, Bure on the Danakil Horst, and at Mt. Ellis;
- associated with major faulting in south-western Ethiopia are the high-alumina basalts of northern Jimma and southern Wollega-northern Ilubabor;
- as already noted, the high alumina basalts of Arussi are hyperalkaline and would seem to be of a different origin from the more typically alkali-poor lavas of high-alumina content.

As an example the average of two analysed high-alumina basalts from the Addis Ababa region is given in Table 5. The norm expresses a high salic content due to enrichment in feldspar at the expense of pyroxene; undersaturation is indicated by the presence of normative nepheline and high normative olivine. The mode of these basalts, which may be either porphyritic or non-porphyritic, reveals the presence of abundant plagioclase (the phenocrysts are strongly zoned) averaging An70, together with olivine, augite and abundant iron-ore minerals.

Lavas showing a strong enrichment in alumina therefore form an important part of the Ethiopian volcanic association. Their relation to the more normal lavas, whether gradational or abrupt, and their apparent restriction to regions of intense tectonic activity, are eminently worthy of further research.

Typical accumulates resulting from the settling of heavy femic minerals during magmatic crystallisation are fairly commonly represented amongst the sub-silicic lavas of the Magdala Group: they have not yet been found amongst Ashangi or Aden lavas, possibly because of the lack of storage of these lavas at shallow depth during their ascent from the Mantle. The average of six Magdala accumulates is presented in Table 5, including augitites, hornblendites and mica-bearing basalts: some of these rocks show the effects of late alteration by solutions rich in volatiles. The chemistry and the norm of these rocks reflects the high femic mineral content observed in the mode, also their undersaturation, and chemical enrichment in water and impoverishment in alkalis and alumina, the last factor being due to the depletion in plagioclase whose crystallisation is delayed when water vapour pressure is high. (Note: no plagioclase-rich lavas have yet been found associated with these accumulates). These accumulates are typical of the great central volcanoes of the Magdala Group, and unlike the high-alumina basalts have no evident tectonic associations.

TABLE 5

Average compositions of some Ethiopian lavas off the main line of fractionation

	1.	2.	3.
SiO_2	46.0	49.2	44.2
TiO_2	1.3	1.0	2.3
Al_2O_3	21.45	8.3	11.0
Fe_2O_3	1.5	9.4	6.0
FeO	7.35	5.5	7.0
MnO	0.1	0.25	0.2
MgO	6.0	6.0	11.2
CaO	10.7	17.1	12.2
Na_2O	2.6	1.75	1.95
K_2O	1.25	0.9	1.25
P_2O_5	0.25	-	0.2
H_2O	1.5	1.4	2.5
Norms:			
Qtz	-	5.5	-
Or	6.9	5.1	6.7
Ab	18.1	14.5	11.9
An	41.3	11.1	16.5
Ne	2.1	-	2.1
Di	7.7	41.3	37.8
Ol	20.0	-	16.1
Wo	-	13.3	-
Ilm	2.1	1.6	3.7
Mt	1.2	7.6	4.9
Ap	0.6	-	0.3

1. Average chemical and normative composition of two high-alumina basalts (Appen. 1, analyses 3 & 4)
2. " two low-alumina basalts (Appen. 1, analyses 45 & 46)
3. " six Magdala accumulates (Appen. 1, analyses 19, 20, 21, 27, 31, 34)

Much more problematical are certain basalts very low in alumina, and differing from the accumulates in being oversaturated. They are especially characterised by an extremely high calcium content. Table 5 lists the average chemical and normative compositions of two such basalts; Hieke Merlin (1950) in making a study of the basalts of Ethiopia in relation to the chemistry of their parent magma, states (footnote p. 35) that she has not considered these Ca-rich Al-poor basalts owing to the impossibility of placing them with any known magmatic type. Since that time, however, the importance of the carbonatitic lavas and intrusives in relation to the African Rift System has begun to be realised; in fact Hieke Merlin herself noted the association of the Beilul basalts with cones of scoriaceous basalt rich in calcite. Although the basalts themselves as studied by Comucci (1928) are not notably carbonated, and therefore contain normative wollastonite; in addition to that contained within the diopside, there can be little doubt of a derivation either from a carbonatitic magma or from a normal alkaline basaltic magma which has suffered carbonatitic contamination.

Chemically these Ca-rich Al-poor basalts are further marked by a very high ferric iron content. When the individual specimens are compared with one another it is found that with increase in Si there are tendencies for increase in ferrous iron, calcium, sodium and water, and decrease in aluminium, ferric iron and titanium: that is, with increasing oversaturation the extreme character of these lavas becomes more marked, and it is suspected that a gradation might be found into a hydro-natro-carbonatite such as occur (but have not yet been analysed or studied) south of Fant-ale.

(c) The evidence for chemical evolution within given lava-types during the Cainozoic in Ethiopia

The availability of numerous analyses of scattered specimens, whilst ill-suited to a study of detailed differentiation processes, is much more favourable to the study of any chemical trends within lava families during long passage of time. Thus far the Cainozoic volcanic history of Ethiopia has lasted through some fifty million years, and it would not seem unreasonable to expect some slight chemical alterations in the fundamental compositions of successive parent magmas. The data presented below strongly suggest that not only have such changes taken place but that they have followed certain unidirectional trends.

(i) The Ashangi and Magdala basalts

Whereas comparisons between the Magdala and Aden lavas can be given for each of the basaltic, intermediate and hypersilicic families, only the basalt family is available for comparison between the Ashangi and Magdala lavas. The restriction of evidence, allied to the uncertainty of the precise field boundary between the two Groups, as well as the different modes of extrusion with evidence of appreciable pre-extrusive crystallisation in the Magdala basalts, make the chemical differences listed in Table 6 somewhat tentative. If changes of less than an arbitrary value of 5 per cent for a given oxide are taken as non-significant, the simple arithmetic increments can be symbolically listed as in Table 9. An added complication is the presence amongst the Magdala basalts of (six) accumulates; the average compositions with and without accumulates are given, but it is considered that the more significant values as related to composition of the original magma is given by the accumulate-free average. Unless stated otherwise any reference to Magdala basalt data are for the accumulate-free average.

TABLE 6

Comparative chemistry of average Ethiopian basalts with time

	16 Ashangi	23 Mag.	17 Mag.	25 Aden
SiO_2	46.6	46.3	47.0	47.3
TiO_2	2.15	2.4	2.4	2.0
Al_2O_3	16.2	14.0	15.1	14.1
Fe_2O_3	3.8	6.0	6.0	6.7
FeO	8.45	6.5	6.3	7.3
MnO	0.23	0.16	0.15	0.20
MgO	6.65	7.4	6.0	5.95
CaO	9.6	10.2	9.5	10.8
Na_2O	2.85	2.65	2.9	2.5
K_2O	1.25	1.7	1.9	1.3
P_2O_5	0.44	0.31	0.34	0.40
H_2O	1.8	2.4	2.4	1.45
Fe^3/Al	0.31	0.57	0.53	0.63
$Fe^3 + Al$	11.2	11.6	12.2	12.2
Fe^3/Fe^2	0.40	0.83	0.85	0.83
$Fe^3 + Fe^2$	9.3	9.3	9.1	10.3
Mg/Fe^2	0.61	0.88	0.74	0.63
$Fe^2 + Mn + Mg$	10.8	9.6	8.6	9.4
Mg/Ca	0.58	0.61	0.53	0.46
Na/K	2.1	1.4	1.4	1.7
Ca/Na/ + K	2.7	2.2	1.8	2.6
Ca + Na + K	10.0	10.6	10.5	10.6
Norms:				
Qtz	-	-	-	0.7
Or	6.9	9.6	10.8	7.5
Ab	24.4	22.9	25.5	21.4
An	26.7	20.3	21.9	22.5
Di	16.2	26.4	21.9	26.5
ol	14.5	10.8	7.0	-
Hy	3.7	0.3	3.1	11.6
Ilm	3.5	4.0	4.1	3.3
Mt	3.2	5.1	5.1	5.6
Ap	0.9	0.6	0.6	0.9

note: the average for 23 Magdala basalts includes six accumulates, which are correspondingly deleted from the average quoted for 17 Magdala basalts.

Primarily, the data of Table 6 reveal the overall similarity of the chemistry of the Ashangi and Magdala basalts sufficient to remark an intimately related source of the parent magmas of the two groups. Thus despite the marked change in ferric/ferrous iron ratio from the Ashangi to the Magdala average basalt, 0.4 and 0.85 respectively, total iron remains little changed at 9.3 and 9.1%. And despite the increase with time in Ca and the variability of both the alkalis from the Ashangi right through to the Aden basalts, the summation Ca + Na + K remains virtually identical at 10.0, 10.5 and 10.6% respectively.

Within this framework of similarity, best exemplified by Si and Si + Al values, the most important changes manifested between the Ashangi and Magdala basalts (and here a consideration of the further changes involved for the Aden basalts cannot be entirely ignored) are the increase in Fe^3/Al and ferric/ferrous iron whilst constant values remain for Fe^3 + Al and total iron; the decrease in Mg/Ca due especially to decrease in Mg (in the non-accumulates); the decrease in Na/K due to a strong increase in K. Also possibly significant are an increase in H and decrease in Mn.

These trends are expressed in the norms in terms of increasingly sodic plagioclase, with transfer of calcium to diopside which increases in proportion (and on into the Aden basalts) at the expense of the simpler femics; orthoclase and magnetite also increase significantly.

The petrogenetic terms underlying these trends can best be considered after a study of the Magdala to Aden basalt-trends.

(ii) The Magdala and Aden basalts

An essential similarity is found for the chemical trends of the Magdala to Aden lavas when each of the three families, basaltic, intermediate and hypersilicic, is considered. For the moment discussion will be restricted to the basalts.

Many of the tendencies observed in the evolution of the Trap Series basalts fail to continue into the Aden Series basalts, despite an overall similarity in the chemistries of all three basalt series. Thus from the Magdala to Aden basalts Ti, K and H decrease and ferrous iron, Mn and P increase, contrary to the Ashangi to Magdala trends; this contrariness is also expressed in the behaviour of the ratios Mg/ferrous iron, Na/K and Ca/Na + K. Whilst a reversal of trends might possibly be expected where a reversion back to fissure-type eruptions occurred, a closer study of the chemistry of the three basalt series reveals that continuing rather than reversing trends are the more significant.

These continuing trends are expressed chemically in increasing ferric iron - that is to say, the degree of oxidation - and increasing Ca, and decreasing Al and possibly Na, but more especially in certain chemical ratios and the norms. Ferric iron/Al and Si/Al increase with time and Mg/Ca decreases, right through the history of the Ethiopian basalts (with the exception noted later of the most recent of the Aden basalts). These trends are summarised normatively in the data for the salic and femic constituents: 58.0, 58.2, 52.1 and 34.4, 34.0, 38.1 respectively. These data seem to indicate a closer affinity of the Ashangi and Magdala basalts. Most significant, however, is the decrease of normative olivine within the Trap basalts with time, and in the Aden basalts olivine disappears entirely from the norm and quartz enters in its place; this increase of silica saturation with time is also found in the silicic differentiates (see section three below), a further argument for genetic intimacy of the basalts and the more silicic lavas of Ethiopia.

TABLE 6a

Norms of Ethiopian basalts (per Table 6) calculated upon the basis of complete non-oxidation, with all iron expressed in ferrous state

	Ashangi	Magdala	Aden
Or	6.8	10.5	7.2
Ab	20.8	18.4	19.1
An	26.1	21.2	21.7
Ne	1.6	3.1	0.8
Di	15.9	21.2	25.7
Ol	24.5	21.0	21.5
Ilm	3.5	4.0	3.2
Ap	0.8	0.6	0.8
% salics	55.3	53.2	48.8
% femics	40.4	42.2	47.2

Classification of basalts according to norm (Yoder & Tilley 1962):

Normative

Qtz + Hy	oversaturated tholeiite
Hy	tholeitte (Hypersthene basalt)
Hy + Ol	undersaturated, olivine tholeiite
Ol	olivine basalt
Ol + Ne	alkali basalt

(note: these are not absolutely separate categories, but distinctions within a single continuum.)

According to the normative classification of basalts by Yoder & Tilley (1962) (see Table 6a) there would seem to be an increasingly tholeiitic character to the Ethiopian basalts with time. This is contrary to the petrographic evidence, and in fact the increase in normative saturation with respect to silica can be shown to be almost entirely due to the increase in oxidation: recalculated norms for the three

Ethiopian basalt series on the basis of complete non-oxidation (Table 6a) reveal that all three have the undersaturated nature of alkaline basalts in conformity with the modes. Because of the abnormally high degree of oxidation of the Ethiopian basalts, particularly in the Aden basalts and Magdala basalts it is pertinent to enquire into the cause of this oxidation. There appear to be three possibilities: (i) a high oxidation within the primary rocks of the Mantle (ii) an increase in oxidation during ascent (or storage) of the magma due to selective crystallisation processes (iii) oxidation of the magma close to or at the surface by connate or free atmospheric oxygen. Possibility (i) must remain speculative but seems unlikely with regard to the wide spatial extent of the Ethiopian Cainozoic volcanic province and the probability that the underlying Mantle is of similar or the same composition as elsewhere beneath Africa. Possibility (ii) could be considered as due, for example, to partial crystallisation processes acting on the magma, either below or above the basalt-eclogite transition, such that there was a larger ferrous/ferric iron ratio in crystals compared with ferrous/ferric iron in the magma and thus the remnant magma would be enriched in ferric iron. Possibility (iii) is an attractive one in view of the disparity of the modes and the norms of the Aden and Magdala, basalts, but whilst there is little doubt that sampling of oxidised surfaces of flows has given rise to some of the high ferric iron values of analysed Ethiopian basalts, this explanation seems insufficient to account for the consistent increase in oxidation of lavas of all compositions. Furthermore, some of the Ethiopian silicic lavas have the occurrence and texture of minor intrusives, but without being notably less oxidised; also, the Magdala lavas, having suffered considerable denudation, are very likely to have been sampled such that specimens of atmospherically oxidised crusts of lava flows will not be proportionately dominant. The problem of the high oxidation of the Ethiopian basalts at present remains unresolved, but it seems improbable that it can be explained in terms of surface or near-surface effects on the ascending magmas; in this context the high water content of the basalts, particularly the Magdala basalts, is noteworthy as at high temperatures water dissociates appreciably.

The increasing normative femicity of the Ethiopian basalts is further emphasised when considered on the basis of complete non-oxidation, values of 40.4, 42.2, 47.2, being obtained for the three series with time (Table 6a), and this together with temporal tendencies of increasing normative Di + Ab against decreasing normative An + Hy + Ol might be taken as evidence of an increasingly alkaline character. It is noteworthy that the hyperalkaline and carbonatitic lavas of Ethiopia are of end-Trappean or more recent age.

Within the normative salic group trends in feldspar composition are not easy to identify owing to the complication from chemical variations of the alkalis and especially K. Generally speaking there is little change in the plagioclase composition, which is labradoritic, except that a high Na/Ca ratio reduces the normative An in the (oxidised) Magdala basalts to give an andesine, though close to the labradorite boundary. Yet there is some evidence for an increasingly sodic composition of the normative plagioclase with time according to the data for non-oxidised basalts and including the most recent Aden basalts (see below). The increase of normative orthoclase in the Magdala basalts is paralleled by the suspected occurrence of sanidine in the mode of many of these lavas.

Within the normative femic group the ratio of normative Di + Hy/Ol increases rapidly with time, and is perhaps the most sensitive factor to time in the evolution of the Ethiopian basalts; it is largely, but not entirely, related to the increasing degree of oxidation, increase in Ca also being responsible. The percentage of molecular Fa in normative Ol (hypothetical in the case of the Aden basalts) varies erratically as 29, 12, 20% with time. The indifferent agreement of normative olivine composition with that observed in the mode - olivine is not commonly present in the Ashangi basalts, is magnesian (20-25Fa) in the Magdala basalts and iron-rich in the Aden basalts (30-40Fa) - must be related to the occurrence of much of the chemical Ti and ferric iron outside the iron-ore minerals, probably in the clinopyroxene.

Normative magnetite increases with time in the Ethiopian basalts; the ilmenite percentage of the total iron-ore progressively decreases.

The fundamental trends in the history of the Ethiopian basalts can be summarised as follows: an apparent increase in silica saturation is due to an increasing degree of oxidation which masks the essentially alkaline nature of all the Ethiopian basalts; the oxidation is incapable of being attributed solely to surficial processes. Evidence for a slight increase in the alkali nature of the basalts with time is accompanied by an increase in calcium, at first sight contradictory but this has occurred in a region marked by the activity of carbonatitic magmas. Soda has increasingly dominated over potash since the Magdala central eruptions: the most recent of the Aden basalts, erupted within the last few hundred years from fissures generally closely associated with the Wonji fault belt and older silicic centres, show an extreme dominance of soda over potash (Na/K 3.0); they also show evidence of being more salic and more undersaturated, and all these factors suggest a reversion to a mode of extrusion, petrography and petrochemistry in conformity with the Ashangi-type basalts. This leads to the tentative suggestion that these latest Aden fissure basalts may mark the commencement of a new magmatic phase in the Horn of Africa. In any case the petrochemical data so far presented indicate that the lavas within the Trap Series bear a greater similarity, for example in their normative femicity, than either the Ashangi or Magdala basalts do to the Aden basalts.

(iii) The intermediate and hypersilicic lavas

The lack of any fractionates associated with the Ashangi basalts (or with the very latest Aden basalts) prevents a confirmation of the trends observed for the Ashangi to Magdala basalts. For the Magdala to Aden transition, however, the more-silicic lavas show chemical trends which remarkably confirm those observed for the basalts. Considering the almost random distribution of analysed Ethiopian lavas, and the many different authors who have made these

analyses (often with different authors analysing the basalts and the silicics from the same region), this agreement of chemical trends for all three compositional families of lavas is the more striking.

TABLES 7 & 8

Comparative chemistry of average Ethiopian intermediate and of average Ethiopian hypersilicic lavas with time

	26 Magdala int.	7 Aden int.	24 Magdala h.sil	26 Aden h.sil
SiO_2	58.9	58.95	70.75	71.15
TiO_2	0.62	0.87	0.44	0.41
Al_2O_3	17.1	15.85	12.65	10.9
Fe_2O_3	3.7	4.3	2.4	2.95
FeO	2.7	3.6	1.8	2.4
MnO	0.23	0.30	0.08	0.14
MgO	0.80	1.1	0.28	0.30
CaO	2.15	3.65	0.69	1.0
Na_2O	6.2	5.8	4.8	5.25
K_2O	4.95	3.5	4.45	4.5
P_2O_5	0.19	0.31	0.11	0.10
H_2O	2.45	1.75	1.6	0.92
Fe^3/Al	0.29	0.36	0.25	0.36
$Fe^3 + Al$	11.7	11.4	8.4	7.8
Fe^3/Fe^2	1.23	1.06	1.22	1.11
$Fe^3 + Fe^2$	4.7	5.8	3.05	3.95
Mg/Fe^2	0.23	0.23	0.12	0.10
Fe + Mn + Mg	2.8	3.7	1.6	2.15
Mg/Ca	0.31	0.25	0.34	0.25
Na/K	1.12	1.47	0.96	1.05
Ca/Na + K	0.18	0.36	0.07	0.095
Ca + Na + K	10.2	9.9	7.7	8.3
Norms:				
Qtz	-	4.8	27.6	27.3
Or	29.6	20.3	25.2	25.4
Ab	53.5	51.6	41.1	31.3
An	4.2	6.9	-	-
Ne	1.1	-	-	-
Ac	-	-	-	7.1
Ns	-	-	-	0.9
Di	5.6	9.1	2.7	4.0
Hy	1.4	1.5	0.3	3.0
Ilm	1.1	1.5	0.8	0.7
Mt	3.2	3.7	2.0	-
Ap	0.3	0.6	0.3	0.3

TABLE 9

Chemical increments for the basaltic, intermediate and hypersilicic lavas of Ethiopia with time

	1.	2.	3.	4.
Si	0	0	0	0
Ti	+	-	+	-
Al	-	-	-	-
Fe^3	+	+	+	+
Fe^2	-	+	+	+
Mn	-	+	+	+
Mg	-	0	+	+
Ca	0	+	+	+
Na	0	-	-	+
K	+	-	-	0
P	-	+	+	0
H	+	-	-	-
Fe^3/Al	+	+	+	+
$Fe^3 + Al$	+	0	0	-
Fe^3/Fe^2	+	0	-	-
$Fe^3 + Fe^2$	0	+	+	+
Mg/Fe^2	+	-	0	-
$Fe^2 + Mn + Mg$	-	+	+	+
Mg/Ca	-	-	-	-
Na/K	-	+	+	+
Ca + Na + K	+	0	0	+

increments 5% ≤ 0

1. Ashangi to Magdala (non-accumulate) basalts
2. Magdala to Aden basalts
3. Magdala to Aden intermediates
4. Magdala to Aden hypersilicics

Table 7 lists the average compositions of Magdala and Aden intermediate lavas, and Table 8 for the Magdala and Aden hypersilicic lavas. Note must be made of the relatively few analyses for Aden lavas of intermediate composition, reflecting the paucity of these rocks in the field. The only Aden centre of silicic lavas which has received even a preliminary study in this respect is the volcano of Fant-ale. This being considered, and also the fact that the greater part of the Aden silicic lavas were extruded prior to the basalts from which therefore they cannot have fractionated (the parent basalts must remain hidden) the common trends shown in the data of Tables 7 and 8 and summarised in Table 9 indicate the operation of fundamental chemical processes during or immediately after magma formation in the upper Mantle.

Most noteworthy amongst the individual chemical oxides are the trends to increase in ferric and ferrous iron, Mn, Mg, Ca and P, and to decrease in Al, alkalis and H, with time for the three families of lavas in the Magdala to Aden transition. The very small increase in Si also noted in each of the three families is too small to be accepted as significant on the present data, despite a tempting consistency. Amongst the chemical ratios, increase in ferric iron/Al and ferric/ferrous iron, Fe + Mn + Mg, Na/K and Ca/Na + K with time occur in all three families of lavas; similarly there are consistent decreases in Mg/ferrous iron and Mg/Ca.

In the norms of the three compositional families there is a consistent increase in silica saturation with time. The appearance of quartz in the norm of the average Aden basalt has already been noted, and how this is due to the high degree of oxidation. For the same reason normative nepheline in the Magdala intermediates is replaced by quartz in the Aden intermediates, and in the Aden hypersilicics normative acmite and natro-siderite appear. However, despite the increase in ferric iron in both the intermediate and hypersilicic lavas with time, the ratio ferric/ferrous iron in both cases shows a decrease (Table 8), and this together with the consistent increase in Ca (in the basalts also) suggests slight increase in saturation and a calc-alkaline tendency with time.

In all three families the total percentages of normative salic minerals decreases:

58.2 to 52.1 for the basalts
88.4 to 83.6 for the intermediates
93.9 to 92.0 for the hypersilicics

Similarly the percentages of total femics consistently increase. This tendency to an increasing femicity with time in the Ethiopian lavas seems to be a fundamental one.

The compositions of the normative plagioclases tend to become more calcic in all three families (considered in their actual oxidised state) - An is absent from the hypersilicic norms but Ab decreases greatly - whilst orthoclase generally decreases, with time. These trends are reflected in an increase in the alkali-lime index from 49 for the Magdala lavas to 52 for the Aden lavas - the figures representing the percentage of SiO_2 at which $CaO = Na_2O + K_2O$.

In summary, the consistency of chemical trends for all compositional families in the Magdala to Aden evolutionary phase is strong evidence for a difference in the chemistry of the parent magmas of these two series. Observed features are a slight increase in saturation (taking oxidation into account), and possibly a slight decrease in degree of oxidation; these facts allied to increasing calcium and therefore increase in the alkali-lime index support the possibility of an increasingly calc-alkaline nature to the Ethiopian lavas with time (but not including the most recent fissure-type basalts of the Aden Series).

4. Conclusions and Comparisions

Unfortunately there are no available comparable data, to those presented above for the Ethiopian Cainozoic lavas, from other parts of the African Rift System or the oceanic ridges with respect to possible chemical evolution with time. Data for the Columbia River tholeiites (Waters 1961, 1962) situated within an orogenic belt, and for the Deccan Traps (Fermor 1934, cited in Turner & Verhoogen 1960, p. 208) situated at the northern end of a disconnected type of oceanic ridge running meridionally from the Maldive and Laccadive Islands, are in both cases too sparse and from too different a tectonic environment to be usefully comparable to the Ethiopian lavas with respect to their temporal evolutions. Yet even here there is the possibility of tendencies to increase in chemical Si and decrease in Al, Mg/Ca; also an increasing femicity of the norm.

It is of interest to note that the chemical trends of the Magdala to Aden transition compare exactly with the data for evolution due to fractionation in the Skaergaard intrusion (Wager 1960), except for the elements Ca and alkalis; it is these elements precisely which would be affected most strongly by any contamination from carbonatitic magma, though it is most unlikely that in the Ethiopian lavas the consistent chemical trends with time should in any way be related to contamination processes. Otherwise the similarity to the results of fractionation in an iron-rich gabbroic magma make it tempting to ascribe such a process, acting slowly at great depth, as accounting for the observed evolution of the Ethiopian basalts; for this to occur there would be required alternating hotter periods of magmatic generation and cooler periods of fractionation at depth.

In summary of the whole of the above discussion:

The Cainozoic volcanic episode in the Horn of Africa has been marked by three phases: a primary phase of flood basalts immediately consequent upon the uplift of the Arabo-Ethiopian Swell, followed by a phase of central basalts together with derived differentiates; a last phase of silicics and recent basalts has been restricted to the floor of the Miocene Rift System except for some minor basalt extrusions on the Plateaux in association with meridional faulting. The Trap Series eruptions of the Oligo-Miocene were on a much larger scale than the later Aden Series eruptions.

Petrography and chemistry indicate the alkaline nature of the Ethiopian Cainozoic lavas, though this tends to be obscured in the chemical norms by the high degree of oxidation encountered. Thus despite the presence of normative quartz in the average Aden basalts they (and the more-silicic lavas) are fundamentally little less under-saturated than the equivalent lavas of the Magdala Group. Many of the chemical trends observed for the Ashangi to Magdala transition are found to be reversed for the Magdala to Aden transition, and this might

be equated with the reversion back to fissure-type eruptions, but in fact there are also some underlying continuing trends: these in particular are increase in normative femicity, due chiefly to increase in total iron content, decrease in Al and therefore increase in Si/Al and ferric iron/Al, notable decrease in Mg/Ca, and although no regular behaviour in alkalis can be discerned there is a slight increase throughout in Ca + Na + K. Chemical trends in the intermediate and hypersilicic lavas from Magdala to Aden types remarkably mirror the trends for the basalts, indicating their genetic intimacy. An increase in calc-alkalinity from the Magdala to Aden lavas may be present, but this is uncertain and other evidence suggests an increase in alkali basalt nature.

Whereas the basalts of the Ashangi Group ascended rapidly and directly from the site of melting in the upper Mantle up new tensional fissures in the young Arabo-Ethiopian Swell, the Magdala and Aden basalts were possibly somewhat restricted in their ascent, not only relatively close to the surface where the characteristic differentiates were formed but also at greater depth where fractionation processes analogous to those at Skaergaard, and including increasing degree of oxidation, may have operated in the chemical evolution of the Ethiopian basalts.

Whilst the theoretical and experimental researches of Yoder & Tilley (1962) indicate the derivation of all basalts, tholeiitic, calc-alkaline, high-alumina and alkali-olivine, from a single source rock in the upper Mantle, with alkali basalts resulting where melting takes place at the greatest depths, yet some difficulties are encountered in this respect when considering the Ethiopian basalts.

Firstly, the evidence from seismic studies (Gouin 1963, in press) suggests that the depth of melting under the Arabo-Ethiopian Swell is 50-60kms., a value concurring with those obtained for the oceanic ridges; though well below the M-discontinuity under the oceans this depth cannot be considered great by continental standards, even where as in the case of the Arabo-Ethiopian Swell it is suspected that the Crust is thinner than normal (author 1962a). It may be noted that there is a secondary concentration of Ethiopian earthquake foci at 30-35kms. Secondly, there is a strong association of the high-alumina basalts and the aluminous silicics in Ethiopia with powerful tectonic lines, particularly with the recent rift-faulting; this fact indicates the separate formation and availability of exceptionally aluminous magmas during the volcanic history of Ethiopia in close proximity to active tectonic lines.

Thirdly, the presence of hyperalkaline lavas in Ethiopia which do not fit simply into the normal basalt differentiation sequence is of interest in the association of many of these with carbonated lavas, and even of natro-carbonated lavas. This supports the postulate of Harkin (1960) that fractionation from an alkali basalt magma is not sufficient to explain the occurrence of the more hyperalkaline and calcium-rich lavas of the African Rift System, and that separate carbonatite magmas have also been active, occassionally causing contamination of the normal lava sequence: which may help explain the apparently contradictory evidence of increasing alkaline and calc-alkaline characters in the temporal evolution of the Ethiopian basalts. A separate derivation of the carbonatites is suggested from their independent activity compared with the alkaline basalts and their fractionates.

The results of the present general survey of the chemistry of the Cainozoic lavas of Ethiopia, and of the regions to the south, suggest that the lavas of the Arabo-African Rift System are more oxidised and hydrated, and have higher Ca/Na + K, than the typical alkali lavas of the oceanic ridges, which share a common tectonic environment. The probability that the oceanic ridge-rift structure of the north-western Indian Ocean enters the Gulf of Aden and thence into Ethiopia via the Gulf of Tajura is very strongly suggested by seismic evidence; chemically the resemblance of the lavas confirms this, and it would seem that a potential oceanic basin exists in the Ethiopian region, supported by the presence of Mantle-type peridotitic rocks on Kod Ali Island.

Acknowledgments

It is hoped that this brief paper will be accepted by English-speaking petrologists as a testimony to the careful, and largely hidden, researches of the many Italian authors who have worked on the petrography and petrochemistry of the Ethiopian lavas.

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Appendix 1. List of analysed lavas from the Horn of Africa, separated according to age and composition.

(a) 16 Ashangi basalts

1. Olivine basalt, Marahano, Eritrea (Manasse 1909)
2. Olivine basalt, St. George's church, Addis Ababa (Rohleder & Hitchen 1930)
3. Basalt, Addis Ababa (Comucci 1932)
4. Porphyritic basalt, Entotto, Shoa (Hieke Merlin 1950)
5. Basalt, Gondar, Beghemeder (Comucci 1950)
6. Basalt, Barga river, Shoa (Duparc 1930)
7. Olivine basalt, Yubdo, Wollega (Duparc 1930)
8. Basalt, Dabu river, Wollega (Duparc 1930)
9. Basalt, Soddo, Wollega (Duparc 1930)
10. Basalt, Karta river, Wollega (Comucci 1948)
11. Basalt, Mt. Kullulu, Arussi (Repossi 1932)
12. Basalt, Gassara, Arussi (Repossi 1932)
13. Basalt, Garamullata, Hararge (Gortani & Bianchi 1937)
14. Basalt, Garamullata, Hararge (Hieke Merlin 1950)
15. Olivine basalt, Mt. Abdulla, Hararge (Hieke Merlin 1950)
16. Basalt, Jarsagoro, Hararge (Hieke Merlin 1950)

(b) 23 Magdala basalts

17. Camptonite, Mai Enda Maruglo, Eritrea (Manasse 1909)
18. Basalt, Meti river, Shoa (Duparc 1930)
19. Olivine basalt, Wadi Sukie, Shoa (Hieke Merlin 1950)
20. Olivine basalt, Wadi Burka, Wallo (Hieke Merlin 1950)
21. Limburgite, Batie, Wallo (Hieke Merlin 1950)
22. Olivine basalt, Mt. Barud, Wallo (Hieke Merlin 1950)
23. Porphyritic basalt, Debra Sina, Shoa (Hieke Merlin 1950)
24. Porphyritic basalt, Gondar, Beghemeder (Comucci 1950)
25. Porphyritic basalt, Manji, Beghemeder (Comucci 1950)
26. Porphyritic basalt, Tulu Goang, Beghemeder (Comucci 1950)
27. Hornblendite, Mt. Selki, Simien (Comucci 1950)
28. Porphyritic basalt, Libo Georgis, Ifag, Beghemeder (Comucci 1950)
29. Doleritic basalt, Kidane Meret, Beghemeder (Comucci 1950)
30. Porphyritic basalt, Consela, Beghemeder (Comucci 1950)
31. Tokeite, Mt. Toke, Shoa (Duparc & Molly 1928)
32. Porphyritic basalt, Tulu Daucu, Wollega (Comucci 1948)
33. Hornblende-biotite basalt, Gore, Illubabor (Comucci 1933)
34. Augitite, Lake Kallu river, Kaffa-Jimma (Duparc & Molly 1927)
35. Basalt, Achevo, Kaffa-Jimma (Comucci 1933)
36. Trachybasalt, Dodola, Arussi (Repossi 1932)
37. Augite-olivine basalt, Curerca, Somalia (Manasse 1916)
38. Olivine basalt, Sheik Gure, Somalia (Aloisi 1927)
39. Augite-olivine basalt, Sheik Gure, Somalia (Aloisi 1927)

(c) 25 Aden basalts

40. Olivine basalt, Alid volcano, Eritrea (Manasse 1909)
41. Olivine basalt, Maraho volcano, Eritrea (Manasse 1909)
42. Basalt, Ghelelli volcano, Eritrea (Comucci 1928)
43. Basalt, Assab, Eritrea (Comucci 1928)
44. Basalt, Beilul, Eritrea (48.84% silica) (Comucci 1928)
45. Basalt, Beilul, Eritrea (49.05% silica) (Comucci 1928)
46. Basalt, Beilul, Eritrea (49.28% silica) (Comucci 1928)
47. Basalt, Bahar Assoli Bay, Eritrea (47.08% silica)(Commuci 1928)
48. Basalt, Bahar Assoli Bay, Eritrea (49.95% silica) (Comucci 1928)
49. Basalt, Assab, Eritrea (45.57% silica) (Ricciardi 1886)
50. Basalt, Assab, Eritrea (46.30% silica) (Ricciardi 1886)
51. Basalt, Assab, Eritrea (46.67% silica) (Ricciardi 1886)
52. Olivine basalt, Bure, Eritrea (Hieke Merlin 1950)
53. Hyalobasalt, Devanji, Gojjam (Comucci 1950)
54. Hyalobasalt, Daga Is., Lake Tana (Comucci 1950)
55. Hyalobasalt, Enjabara, Gojjam (Comucci 1950)
56. Porphyritic basalt, Mosha, Gojjam (Comucci 1950)
57. Porphyritic basalt, Ismala Georgis, Gojjam (Comucci 1950)
58. Basalt, Walenkiti, Shoa (Hieke Merlin 1950)
59. Olivine hyalobasalt, Ajelu volcano, Hararge (Hieke Merlin 1950)
60. Basalt, Aisha, Hararge (Hieke Merlin 1950)
61. Basalt, Farso, Hararge (Hieke Merlin 1950)
62. Olivine basalt, Mt. Iddidlei , Hararge (Hieke Merlin 1950)
63. Basalt, Farso, Hararge (Gortani & Bianchi 1937)
64. Olivine basalt, Kandala, Somalia (Aloisi 1934)

(d) 26 Magdala intermediates

65. Tinguaite, Azeo Mareb, Eritrea (Manasse 1909)
66. Liparitic tuff, Mai Metere, Adi Ugri, Eritrea (Manasse 1909)
67. Solvsbergite, Edda Georgis, Adua (Prior 1900)
68. Tinguaite, Edda Georgis, Adua (Prior 1900)
69. Anorthoclase trachyte, Addis Ababa (61.78% silica) (Comucci 1932)
70. Anorthoclase trachyte, Addis Ababa (62.68% silica) (Comucci 1932)
71. Trachyte, Addis Ababa (Rohleder & Hitchen 1930)
72. Nepheline phonolite, Enjabara, Gojjam (55.04% silica) (Comucci 1950)
73. Nepheline phonolite, Enjabara, Gojjam (56.56% silica) Comucci 1950)
74. Nepheline trachyte, Amba Libo, Ifag, Beghemeder (60.57% silica) (Comucci 1950)
75. Nepheline trachyte, Amba Libo, Ifag, Beghemeder (61.85% silica) (Comucci 1950)
76. Sodic trachyte, Gondar, Beghemeder (Comucci 1950)
77. Phonolitic trachybasalt, Mt. Belmodo, Beni Shangul (Muhlen & Hellmers 1936)
78. Phonolite, Mt. Belmodo, Beni Shangul (Muhlem & Hellmers 1936)
79. Trachyandesite, Mt. Katta Jorgo, Wollega (53.31% silica) (Comucci 1948)
80. Trachyandesite, Mt. Katta Jorga, Wollega (54.22% silica) (Comucci 1948)
81. Sodic trachyte, Gore, Ilubabor (Lacroix 1930)

82. Bostonite, Tulu Jergo, Wollega (59.70% silica) (Comucci 1948)
83. Bostonite, Tulu Jergo, Wollega (60.08% silica) (Comucci 1948)
84. Alkaline trachyte, Bube, Wollega (Comucci 1948)
85. Anorthoclase trachyte, Bure, Ilubabor (Duparc 1930)
86. Kenyite, Billo, Wollega (Duparc & Molly 1928)
87. Solvsbergite, Karsa, Hararge (64.42% silica) (Lacroix 1930)
88. Solvsbergite, Karsa, Hararge (65.14% silica) (Lacroix 1930)
89. Sodic trachtye, Guma graben, Sardo, Afar (Hieke Merlin 1953)
90. Tinguaite, Allengo, Somalia (Manasse 1916)

(e) 7 Aden intermediates

91. Sodic trachyandesite, Assacoma, Eritrea (De Angelis 1925)
92. Sodic trachyte, Gaharre, Eritrea (De Angelis 1925)
93. Dancalite, Assacoma, Eritrea (De Angelis 1925)
94. Trachyte, Bahar Assoli Bay, Eritrea (Comucci 1928)
95. Alkaline trachyte, Adama, Shoa (Repossi 1932)
96. Sodic olivine trachyte, Fantale volcano, Shoa (Lacroix 1930)
97. Trachydolerite, Enjabara, Gojjam (Comucci 1950)

(f) 24 Magdala hypersilicics

98. Bostonite, Senafe, Eritrea (Manasse 1909
99. Paisanite, Amba Tokile, Eritrea (Manasse 1909)
100. Quartz bostonite, Senafe, Eritrea (Mansse 1909)
101. Quartz bostonite, Barakit, Eritrea (Manasse 1909)
102. Sodic rhyolite, Mehra Seitan, Tigrai (Merla & Minucci 1938)
103. Obsidian, Amba Berra, Adua (Prior 1900)
104. Grorudite, Amba Sibat, Adua (Prior 1900)
105. Paisanite, Amba Sheloda, Adua (Prior 1900)
106. Quartz prophyry, Ifag, Beghemder (Comucci 1950)
107. Comendite, Mt. Kicha, Beghemder (Comucci 1950)
108. Comendite, Mai Shaha valley, Simien (Comucci 1950)
109. Alkaline rhyolite, Balisa, Wollega (Comucci 1948)
110. Comendite, Baro river, Ilubabor (Comucci 1948)
111. Liparite, Mil Millacat, Wallo (Hieke Merlin 1953)
112. Comenditic liparite, Utchali, Wallo (Hieke Merlin 1953)
113. Comenditic liparite, Lake Haik, Wallo (Hieke Merlin 1953)
114. Trachyliparite, Lake Haik, Wallo (Hieke Merlin 1953)
115. Trachyliparite, Debra Berhan, Shoa (Hieke Merlin 1953)
116. Comenditic liparitic obsidian, Entotto, Shoa (Hieke Merlin 1953)
117. Pantellerite, Addis Ababa (71.37% silica) (Rohleder & Hitchen 1930)
118. Pantellerite, Addis Ababa (71.91% silica) (Rohleder & Hitchen 1930)
119. Comendite, Addis Ababa (Comucci 1932)
120. Pantellerite, Mt. Kakka, Arussi (Repossi 1932)
121. Solvsbergite, Karsa, Hararge (Lacroix 1930)

(g) 26 Aden hypersilicics

122. Pantellerite, Bahar Assoli Bay, Eritrea (De Angelis 1923)
123. Comendite, Bahar Assoli Bay, Eritrea (De Angelis 1923)
124. Amphibole felsodacite, Alid volcano, Eritrea (Manasse 1909)
125. Liparitic obsidian, Alid volcano, Eritrea (Manasse 1909)
126. Porphyritic liparite with tridymite, Badda-Samoti, Eritrea (Manasse 1909)
127. Liparite, upper Borkenna valley, Wallo (Hieke Merlin 1953)
128. Comenditic liparite, Mojjo, Shoa, (Hieke Merlin 1953)
129. Patelleritic obsidian, Mojjo, Shoa, (Rohleder & Hitchen 1930)
130. Pantellerite, Metahara, Shoa (Rohleder & Hitchen 1930)
131. Pantellerite, Fant-ale volcano, Shoa (Rohleder & Hitchen 1930)
132. Obsidian, Fant-ale volcano, Shoa (69.06% silica) (Lacroix 1930)
133. Porphyritic obsidian, Fant-ale volcano, Shoa (70.52% silica) (Lacroix 1930)
134. Obsidian, Fant-ale volcano, Shoa (71.30% silica) (Lacroix 1930)
135. Granophyre, Fant-ale volcano, Shoa (67.30% silica) (Lacroix 1930)
136. Granophyre, Fant-ale volcano, Shoa (69.86% silica) (Lacroix 1930)
137. Aegerine pantellerite, Fantale volcano, Shoa (Lacroix 1930)
138. Trachyliparite, Miesso, Hararge (Hieke Merlin 1953)
139. Trachyliparitic tuffaceous obsidian, Miesso, Hararge (Hieke Merlin 1953)
140. Trachyliparite, Mt. Ellis, Hararge (64.96% silica) (Hieke Merlin 1953)
141. Trachliparite, Mt. Ellis, Hararge (66.80% silica) (Hieke Merlin 1953)
142. Trachyliparite, Gawani, Hararge (Hieke Merlin 1953)
143. Comenditic liparitic obsidian, Ajelu volcano, Hararge (Hieke Merlin 1953)
144. Comenditic liparitic obsidian, Sardo, Afar (Hieke Merlin 1953)
145. Pantellerite, Dabita, French Somaliland (Lacroix 1930)
146. Pantellerite, Hol Hol, French Somaliland (Lacroix 1930)
147. Comendite, Mt. Mabla, French Somaliland (Lacroix 1930)

HIGH ALTITUDE CLOUDS OVER ADDIS ABABA

L. R. PITTWELL*

Abstract:

Nacreous and noctilucent clouds have been observed over Addis Ababa (09°N, 39°E) and vicinity. They have been sighted both after sunset and before dawn. On rare occasions, nacrous clouds have been observed in daylight and by star or moonlight. Analysis shows that they contain water.

It is probable that these clouds are due to South-Easterly Trade winds over-riding lower winds and being forced still higher by turbulence over the Ethiopian Rift System. They are typical lee clouds except for their exceedingly high altitude.

Description:

Two distinct types of cloud or haze, of probably similar origin, have been noticed at sunset and sunrise over Addis Ababa, producing unusually long twilight times. The commonest type (a) consists of a bank or banks of clouds at from 10-50km. Rarer, but more spectacular, (b) is huge dome-like cloud at higher level, usually at from 95-160km. Only on three occasions has there been any evidence of cloud between these layers, which must be separated by the warm zone at the top of the stratosphere.

(a) The lower type takes the form of rays or ripples, and sometimes banks, high above any cirrus or alto-stratus. They are pearly white when seen by day or night, and go through the same sunset colours as other lower high clouds such as cirrus.

Normally, they are tenuous and only directly visible at sunset or sunrise. On occasions, however, when sufficiently thick, they have been observed up to three hours before sunset and four hours after sunrise; when illuminated either by the moon or a planet such as Jupiter, they have been seen for at least six hours after sunset. They may also be observed by watching for an anomalous lightness of the blue at zenith or unusual dimming of the stars. Normal density clouds obscure all stars below 3rd magnitude; dense clouds may obscure stars and planets up to second magnitude.

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Such dense clouds can throw shadows unto lower banks of alto-stratus and cause the clouds to the East of them to go through the sunset colours twice, which might cause spurious reporting of noctilucent clouds. The second change is duller than the first and so can be distinguished for lower clouds; dome clouds (type b) so lit can glow faintly as long as 75 minutes after sunset making altitude determinations impossible.

These lower clouds are normally seen as bright stripes converging to two points well below the horizon about 180° apart. They may be sub-divided roughly into four groups if one considers the azimuth in the first half of the horizon towards which they converge: (See lower section of Fig. 2).

North and South	(350° - 30°)
" "	(60° - 75°)
East and West	(85° - 95°)
ESE and WNW	(115° -135°)

There are also a few variant forms, the commonest being a solid bank, usually NW of the city, with often ray-like clouds running out of it eastwards. These clouds, in a few instances, have been crepuscular rays, but on many occasions, their rays did not converge towards the sun. Rays have also been seen to cross over each other at different levels, or to have the top or bottom surface rippled transversly.

Some rays have been seen to curve following roughly the run of the Rift. One such cloud appeared over the Ankober Scarp (see map) and resembled a segment of a dome with the lower edge following the bend in the scarp and the higher portion covering the plateau, north and west of the scarp. On one occassion, a long east-west ripple cloud, almost due north of the city, was observed to have a huge cylindrical tower rising from the top to a height of 70-75km above the earth.

When the clouds are between 10-25km, it is sometimes possible to notice a little graininess or feather-like wings, similar to formations seen in cirrus and and stratus clouds at lower levels. Such clouds have never been seen to drift.

(b) Only once (Jan. 17, 1963) during the present series of observations has a noctilucent cloud typical of illustrations in textbooks been observed. It was a long wavy streamer far to the East of Addis Ababa, in the direction of the Ankober Scarp. Its altitude was estimated at 90-100km.

The usual high altitude phenomenon appears as a glow which may last for over one hour after sunset. This glow is similar to that from the banks described above but ends with a deeper red coloration presumably due to the longer light path, and therefore to greater absorption in the atmosphere. Seen from Addis Ababa, this glowing cloud usually covers the whole sky, but partial cover has also been observed either over the Rift or the Entoto and its edge somewhat followed the shape of the escarpment. Seen from the south side of the Rift, at Assella or Boccogi, it appears as a huge red inverted dome stret-

ching from Ankober in the east to Addis Alem in the west with a flattish top slightly to the east of, or right over, Addis Ababa. Long exposure photographs of the northern horizon on cloudness nights reveal that this glow is similar to that from alto-stratus clouds, that its density is not uniform, and that the colour, from west to east, goes from orange, through red, to deep reddish purple. These colours resemble sunset rather than aurora.

These glowing clouds may cause very intense and prolonged backlighting of lower clouds.

Calculation of altitude based on the assumption that the colour is due to direct illumination from the sun always give results higher than 60km. Figures above 120km are unreliable because of the difficulty in distinguishing back scattered light from direct illumination.

Both types of high and low altitude clouds have also been observed at dawn, but the frequency of occurrence of the different types is reversed: the dome type is commoner and more spectacular in the dawn than at dusk. Some 60-40 minutes before sunrise, and preceeding the direct illumination of normál altitude clouds, an almost uniform wash of very intense purple sweeps over the sky from the East, close to the sunrise point, soon becomes deep red, and then goes through all the intermediate shades of orange and creamy white before fading to the usual blue of the sky. The west side of low clouds was observed to be illuminated by the light scattered from this high altitude dome prior to the direct illumination of their east side.

All told, out of 388 days of observations:

a) Type (a) clouds were observed on 169 occasions.
b) Type (b) of upper altitude clouds were observed 36 times.
c) Accurate measurement of elevation was possible on 359 days.
d) About 35 observations were made at dawn.

Table I and Figure II give a comprehensive picture of sky conditions, estimated altitude, and bearings of the clouds as observed from December 1962 to the end of 196

Altitude measurement:

Altitude was estimated by sunset delay method, i.e. by measuring the time delay between surface sunset and cloud sunset at the meridian and by calculating the height necessary to account for the delay. A check on this method was obtained by triangulation with base-lines of 100 and 170km, and the results agreed within 10%.

Ludlam (1963) has remarked that the sunset delay method tends to give lower results because of refraction; correction however was not applied.

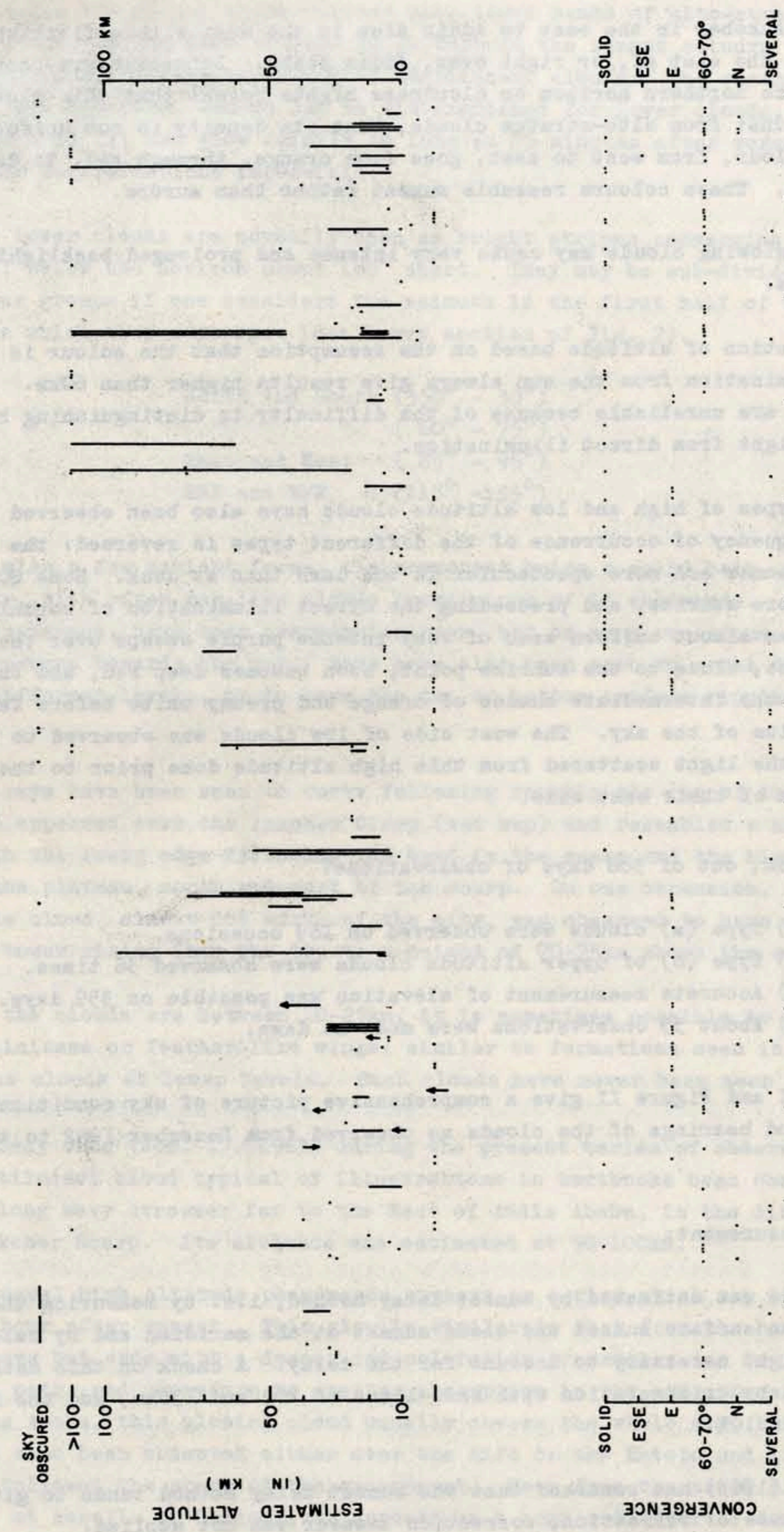


Fig. 2 Sky conditions, estimated altitude, angle of convergence, and general distribution of high altitude clouds observed over Addis Ababa from December 1962 to the end of 1963.

TABLE I

FREQUENCY OF RIPPLE PATTERNS AND THEIR BEARING OF CONVERGENCE TOWARDS THE EASTERN HALF OF HORIZON

MONTH	Approx. N - S	Approx. 60 - 70°	Approx. E - W	Approx. ESE	SOLID
December 1962		6			
January 1963	5	8	2		1
February	2	7	1		
March	7	14	3		
April			3	2	4
May	1		8	3	4
June	2		1	1	1
July	2	4	7	2	17
August	1	2	2	3	6
September			5		1
October	1	12			
November	1	11	2		3
December	5	14	0	2	6

Suggested explanation:

Topography of the region:

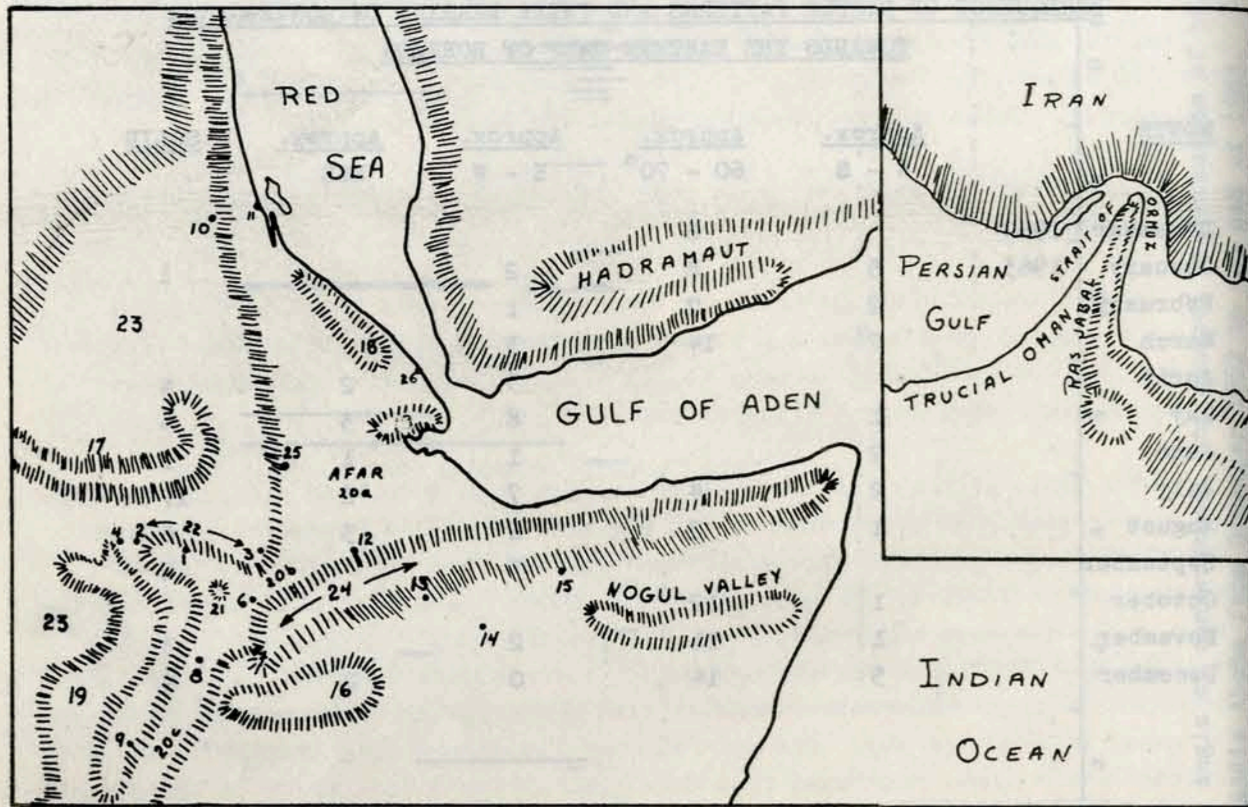
The general topography of Ethiopia (Map 1) is mainly governed by a system of deep rifts sharply separating the Ethiopian, Somalian, and Arabian Plateaus. In the North-East is the Afar Depression whose steep western boundary runs almost due North from the latitude of Addis Ababa; the ENE-WSW Scarp of the Somalian Plateau and the Chercher mountain range (24) marks its southern limits. From the S.W. corner of the depression N.E. of Addis Ababa, the Main Ethiopian Rift emerges bending slightly southwards and then heads S.S.W.

On the N.W. and S.E. sides of this huge funnel are the high plateaus.

At the bend in the Main Ethiopian Rift there are two important bays: one to the N.W. with Addis Ababa (1) on its upper northern side, and to the S.E. a small semi-circular pocket with Boccogi (7) on its extreme S.E. slope. Both bays are above the floor of the Rift proper and are rimmed by high mountains, 10,000-12,000 feet high in the vicinity of Addis Ababa, and up to 14,000 feet around Asella and Boccogi (7).

Laboratory experiment:

A three-dimension topographic rough surface scale model of the region around Addis Ababa was built and sunk to the bottom of a large water tank.



SKETCH MAP (not to scale)

1.	Addis Ababa	10.	Asmara	19.	Omo Rift
2.	Addis Alem	11.	Massawa	20.	a. Afar Depression b. Awash Valley c. Ethiopian Rift
3.	Ankober	12.	Dire Dawa		
4.	Hagere Hiywot	13.	Harar	21.	Zukuwala
5.	Nazareth	14.	Jigiga	22.	Entoto Ridge
6.	Sodere	15.	Hargeisa	23.	Ethiopian Plateau
7.	Boccogi	16.	Bali Mts.	24.	Chercher Mts.
8.	Sheshamane	17.	Abbai Canyon	25.	Dessie
9.	Chenchia	18.	Danakil Horst	26.	Assab

Uniform directional steams of water were directed over the model. The model was rotated to simulate different directions of flow.

The experiment was repeated at different depths and flow rates.

Observations could be classified as follows:

1) Only with flows from the South-East could ripples be produced over Addis Ababa. Slight changes in direction of the flow produced very marked changes in the alignment of the ripples, the patterns roughly corresponding in alignment to the cloud directions mentioned above (type a).

Conversely, ripples could be produced South of the Bali mountains (16) with a northwesterly flow. The fact that no ripple clouds are reported from that region may indicate that the wind does not flow from the N.W. over the Wabi Shebelli Valley.

2) No ripples could be obtained when the flow was directed over a single scarp, as for instance, an easterly flow from the Gulf of Aden onto the steep western scarp of the Afar Depression.

3) In addition, south-easterly flows produced a pronounced swelling of the water in the bay around Addis Ababa and over the Entoto Ridge from about Ankober (3) on the model to Addis Alem (2). This swelling was accompanied by an immense upthrust. Ink released close to the surface of the model South of the Bali mountains (16) was either swept over the south-eastern scarp and along the floor of the Rift, or up to the surface of the wave over the Entoto Ridge (22). The water flow was highly turbulent and from time to time, spiral eddies would form N.W. of the Rift, similar to the tower cloud sighted once above the ripple clouds.

Confirmatory Field Observations:

Observations made at Addis Ababa as well as other various locations in Ethiopia, for instance, in Sheshemane (8), Boccogi (7) Hagere Hiywot (4), Gendebret, and Dessie reveal an almost perfect correlation between the high altitude clouds position and patterns and the water waves produced in the ripple tank experiment.

Moreover, reports from the Jigiga-Harar-Dire Dawa area indicate a pronounced upthrust of humid air from the South East, rising over the Chercher mountains (24); the upper layers form banks of cirrus and stratus, often rippled, which continue to rise at an angle of 35^{o} or more, over the Rift in the direction of the plateau. Over Dire Dawa, in summer, the bottom of these clouds was estimated to 10km while the top reached 50km. They were sufficiently high to cause a 10-15 minute prolonging of twilight at Harar and much longer at Dire Dawa. It is significant, also, that on these nights both types of clouds (a and b described in the first part of this paper) were observed over Addis Ababa.

Additional evidence for a piling up of air over the region is provided by the positive anomaly in atmospheric pressure values: at the Geophysical Observatory in Addis Ababa the atmospheric pressure is reported to be constantly about 15mm Hg above normal.

The existence of turbulent upthrust is also confirmed by the behaviour and distribution of high banks of cumulus. From the high plateau, North of Addis Ababa, immense banks of cumulus can be seen along both rims of the Rift, at the bend near the city, around Debre Sina, and far to the North towards the Simien mountains. Such tower cumulus are often driven through the cirrus above and their tops are swept up into an immense zone of haze. Nacreous clouds have been observed in and above this hazy zone.

High altitude cloud phenomena are also reported from other regions of similar topographical features, for instance, from Northern Ethiopia along the escarpment (13°- 14°N) as well as about 25km West of Assab (26), the Danakil Horst forming the windward slope of the valley in both cases; from Hargeisa (15) in the Nogal Valley (Somalia) between the Coast Range and the Dan Guba; they are also reported on the coast of Trucial Oman where the Ras el Jebel, the Strait of Ormuz; and the mountains of the Persian coast form a similar narrow rift.

Discussion:

The fact that the model only gave ripple patterns with flows from a south-easterly direction and that slight variations in the direction of this flow could produce most of the various observed ripple patterns is significant. The South East Trade winds blow across the Indian Ocean and then, either meet the wind blowing out from the high-pressure area that forms in the winter south of the Himalayas, or is diverted by the High that forms in the Arabian Sea West of India in May-June or in the autumn,and swings round North of the Equator to bring a south-westerly monsoon to India. Presumably at least some of this air must over-ride the other airstreams and cause upper atmosphere turbulence over the Ethiopian Rift. This would explain why the changes in the ripple patterns obtained coincide with the periods of high pressure over the Arabian Sea and the Punjab.

The rains during the Ethiopian Krempt (June-September - greater rains) are usually attributed to high pressure over West Africa causing southwesterly wet winds to drive onto the plateau across Sudan and reach the region of Addis Ababa. At the same time, the direction of surface winds South of the Chercher (24) and at Chenchia (9) in the southern part of the Rift was reported as southerly or south-easterly. These surface air currents coming from different directions produced a confused pattern of ground winds in the region of Addis Ababa and presumably increased the uplift.

Scorer (1961) has studied the formation of high clouds on the lee side of hill slopes. He showed that in the Owens Valley, between the Sierra Nevada and

the Panamint mountains, the turbulence forms clouds at 10-15km. The Ethiopian Rift is similar to Owens Valley, but wider and in places, deeper. The cloud phenomena described in this paper closely agree with Scorer's observations except for their much greater altitude and this difference may well be accounted for by the greater separation of the ranges.

The Nazareth area (100km S.E. of Addis Ababa) on the floor of the Rift is known for its whirlwind-like dust storms which, whilst different from the dust rollers in the lee of the Sierra Nevada described by Scorer, are however quite similar to the turbulence patterns observed in the scale model experiment.

On three occasion, first before or after sunset, the nacreous type clouds described have been examined by the author with a small comparison spectrometer. This type of spectrometer enabled the spectra of two sources mutually at right angle relative to the observer, to be compared. First, it was possible to identify the water absorption bands in sunlight relected from a cumulonimbus cloud, using the Fraunhoffer lines in the sun's spectrum as a wavelength guide. Then, the absorption bands in the nacreous cloud were found to be identical to those in the cumulonimbus cloud; moreover, the absorption in the spectra from both clouds was many times greater than in the spectra from patches of clear blue sky adjacent to both clouds. (Pittwell, 1963). This spectral observations confirms the Swedish postulations from recent rocket experiments that such clouds contains ice crystals (Soberman 1963).

Hesstvedt (1960) had already suggested that similar sub-arctic upper atmosphere clouds (82km) might also contain ice crystals. He has also calculated that nacreous clouds could occur at the tropics (1963) at up to 20km. This would account for the clouds in the 6-20km section of the lower range. The strong upthrust of humid air into higher regions of lower pressure could cause Joule-Thompson cooling and therefore explain the formation of clouds in the upper regions.

Suggestion has been made also that these clouds consist of dust particles. Hoffmann reports that dust storms in the northern Arabian deserts at least, never throw dust higher than 10,000feet, and also that dust clouds are darker than nacreous clouds. The author also noticed that the clouds after the war-time Burton-On-Trent explosion had an unusually dark brown or greenish tinge. Anyway, it is the author's belief that the amount of surface dust raised by the whirlwinds from the floor of the Ethiopian Rift is insufficient to form more than nuclei for a cloud.

It is possible that the deep red colour of the evening dome cloud may be partially due to emission from excited molecules not normally present at this altitude, swept up by the turbulence. However, the uncertainty of the appearance , of this type of cloud and the lack of a suitable spectrograph make this impossible to determine. The dawn dome cloud is most likely due to sun-lighted particles, as it is very bright and shows sunset colours in reversed order.

These observations indicate that, even if the high altitude clouds described do contain some dust, it must be very fine indeed and be responsible for only a very small proportion of the reflected light, the greatest part being reflected by water in some form or other. The presence of humidity at altitudes as high as 100km over Addis Ababa is easily explained if the 35° upthrust observed on humid clouds leaving the North edge of the Chercher mountains continues all the way across the Rift.

Conclusion:

To recapitulate, it is concluded that nacreous and noctilucent clouds can be formed by wet winds blowing across deep steep-sided valleys. Such valleys must be of optimum depth and width to produce turbulence that will increase the normal lee uplift from the mountain on the windward side of the valley. Moist air is thus forced to great heights with additional cooling by expansion. Under such conditions all types of clouds may be found at altitudes above normal and nacreous and noctilucent clouds form over the valley and in its lee.

The nacreous clouds are often rippled due to the turbulence; noctilucent clouds, on the other hand, are shaped like the top of a wave or a dome.

Acknowledgments:

To reduce the personal error factor as much as possible, the author has used a system of multiple independent witnesses. I am therefore indebted to several undergraduates, to my family, to Mr. K. Gullman, Dr. Rupert, and the hospital Staffs at Boccogi, Hagere Hiywot, Gendebret and Batie for observations in Ethiopia; to Mr. J. Seymour for observations from Trucial Oman and Somalia, and to Mr. and Mrs. R. Logan-Reed for observations from Somalia.

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GENERAL REPORT ON AN EXPEDITION TO THE SIMIEN MOUNTAINS

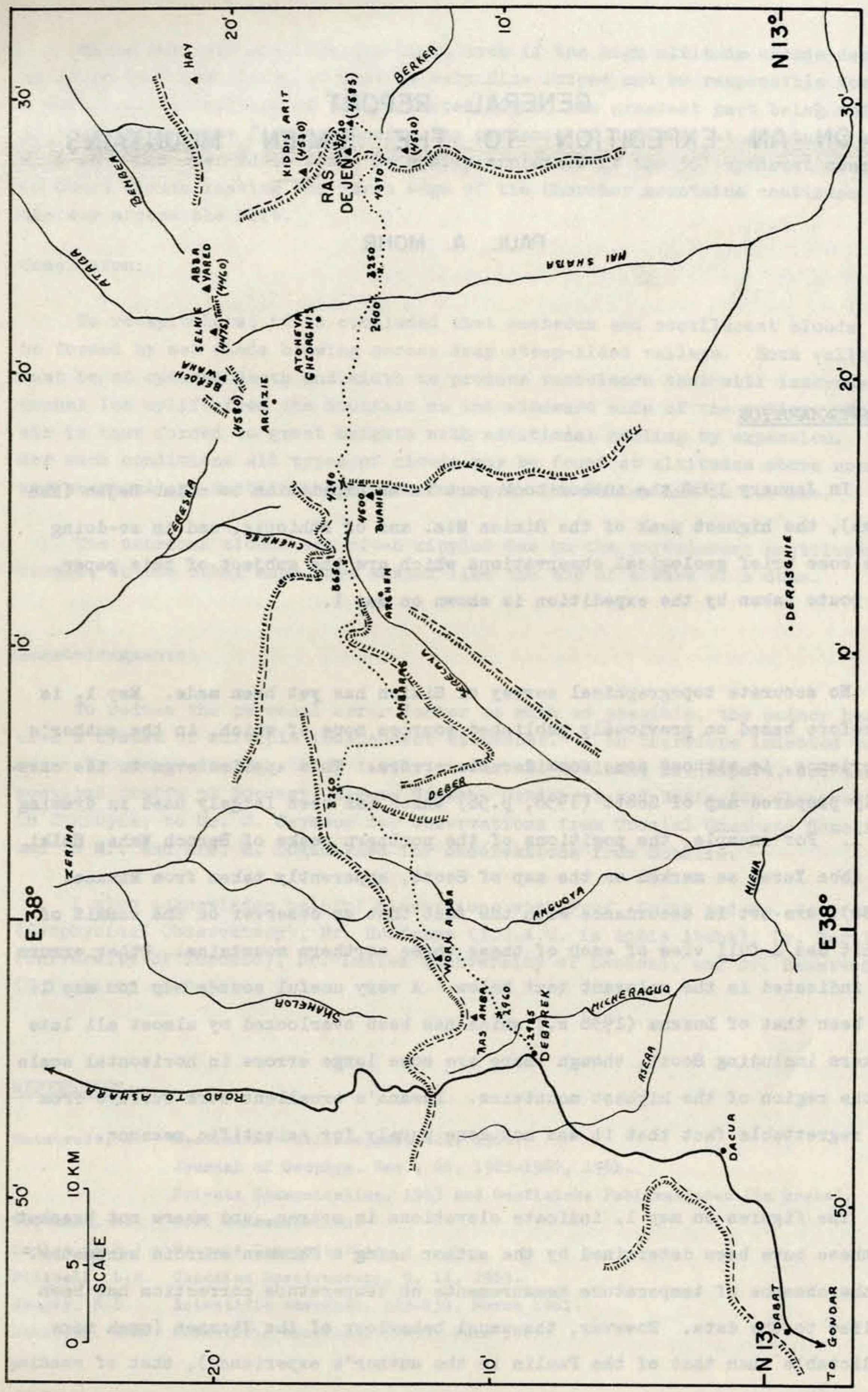
PAUL A. MOHR

1. INTRODUCTION

In January 1962 the author took part in an expedition to climb Dejen (Ras Dejen), the highest peak of the Simien Mts. and of Ethiopia,. and in so-doing made some brief geological observations which are the subject of this paper. The route taken by the expedition is shown on map 1.

No accurate topographical survey of Simien has yet been made. Map 1. is therefore based on previously published sources none of which, in the author's experience, is without some considerable errors. This applies even to the carefully prepared map of Scott (1958, p.58) which has been largely used in drawing map 1. For example, the positions of the northern peaks of Beroch Waha, Selki, and Abba Yared as marked on the map of Scott, apparently taken from Minucci (1938), are not in accordance with the fact that an observer on the summit of Buahit has a full view of each of these three northern mountains. Other errors are indicated in the relevant text below. A very useful source map for map 1. has been that of Lusana (1938 a.) which has been overlooked by almost all late workers including Scott, though there are some large errors in horizontal scale in the region of the highest mountains. Lusana's excellent work suffers from the regrettable fact that it was not done purely for scientific reasons.

The figures on map 1. indicate elevations in metres, and where not bracketed these have been determined by the author using a Thommen aneroid barometer. In the absence of temperature measurements no temperature correction has been applied to the data. However, the usual behaviour of the Thommen (much more predictable than that of the Paulin in the author's experience), that of reading



Map 1: Expedition to the Simien Mountains.

too high as the day proceeds by up to 50m. by late afternoon, will have been tended to be cancelled on Simien where on every day that measurements were made altitude was gradually gained to regions of lower temperature. The only exception to this was the descent to the Mai Shaha where the reading is certainly too high, by perhaps 40m.. Furthermore, at the generally high elevation of Simien the diurnal variations in barometric pressure will be very small (see meteorological reports for Addis Ababa, 2440m, in the Bulletins of the Geophysical Observatory of Addis Ababa).

It remains to state that the agreement of the author's elevation data with those of previous workers is extraordinarily close. The value obtained for the highest peak, Dejen, was 4620±5m., the accepted figure. Whatever large errors aneroid barometers are subject to in measuring elevation it seems that these are consistent from one type to another. However, a proper geodetic survey of Simien is eminently desirable.

2. OBSERVATIONS ON THE SOLID GEOLOGY

Debarek (2985m.) which was the base of the expedition, is situated upon Trap Series flows derived from the Simien volcanic centre, active during the late Oligocene or early Miocene. The Trap Series as exposed between Gondar and Debarek is very predominantly composed of basalt lavas, frequently amygdaloidal and rich in zeolite, with some interbedded basaltic tuffs. However, at least two thin trachytic lava and tuff horizons are exposed within this thick basaltic series, which shows a slight but definite tendency to dip southwards, probably an original expression of the slope of the ancient Simien volcanic cone.

At 7km E.N.E. from Debarek, just south of Ras Amba*, a double fault scarp is preserved with only small erosion gullies cutting the parallel scarps, though the lower one has suffered more from stream dissection. The Micheraguo stream flows south along the base of the fault-scarps, which trend N.N.E.-S.S.W. and are downthrown west, exposing the usual coarsely porphyritic basalts and basaltic tuffs of this district. The line of faulting may extend northwards along the Shemeloa valley as well as south down the Micheraguo valley; it is evidently fairly recent in age.

*Between Debarek and Ambaras, the map of Lusana is more accurate than that of Scott.

In the Anguova and Deber valleys, upper tributaries of the Mai Beleghes which have cut back north-westwards to the main west-facing boundary precipice of Simien, a sub-horizontal succession of at least thirty basalt flows with some intervening coarse tuffs is exposed. The basalts include the dark, dense holocrystalline type characteristic of the stratoid lavas of the planar regions of the Ethiopian Plateau, but are chiefly of the porphyritic and vesicular varieties; the phenocrysts of the porchyritic basalts are usually feldspar but can include pyroxene. It would be useful, in any future survey of the Simien Mts. geology, to count and label the basalt flows and trace their individual extent over the massif; indeed, this is an urgent requisite in the study of the Trap Series of Ethiopia as a whole.

Between Debarek and the Deber valley there can be no doubt that the scale of the British War Office 1:500,000 maps* (Gondar and Macalle sheets) is in considerable error, for it is a day's march from Debarek to the Deber col (3260m.), and again a day's march over similar going from the Deber col to near Arghen (3650m.) The map of Lusana (1938 a.) shows the scale much more exactly, and without the gross exaggeration of the size of the Ambaras massif that appears in Scott (1958). The village of Arghen lies at the head of the Serecava valley (marked Serecaca on the 1:500,000 map).

The route from Deber to Arghen reveals splendid views of the Buahit range, composed of basaltic flows dipping very gently to the south and thus determining the remarkably even slope of the ridge from Buahit at its northern end down southwards towards Derasghie. The number of flows exposed in the Serecava valley below Ambaras village is at least one hundred; in this valley massive amygdaloidal, porphyritic trachybasalts and light-coloured tuffs, overlying dark porphyritic basalts, are themselves overlain by thinner flows of dense holocrystalline basalt which is sometimes vesicular. Numerous basaltic dykes cut the lava series in a N.E.-S.W. direction.

Immediately north of Arghen, on the north-west side of the Serecava canyon, coarsely vesicular basalt is exposed resting upon light porphyritic trachybasalt and light-coloured flow-structured tuffs. The vesicular basalt is very similar in appearance to the Aden Volvanic Series lavas of Beni Shangul and the Abbai basin, and to a flow discovered by the author on Dejen described below.

*Therefore the map of Scott, being based on these War Office maps, is similarly in error, though the upper tributaries are not named nor marked on his map.

The path from the Serecava valley up to the serrated, knife-edged north shoulder of Buahit exposes dark vesicular basalts with at least one interbedded porphyritic trachybasalt horizon. Magnificent but inaccessible exposures of these lavas occur on the stupendous precipices of the Chennec valley (see Scott 1958, Plate 12). To reach the flat summit of Buahit (4500m.) from the north col at 4290m., four or five flows of amygdaloidal basalt, rich in agate cavities, are surmounted, all cut by a complex pair of holocrystalline basaltic dykes each about 2 metres across, trending N.-S., and with unusually good examples of tachylite selvages up to 3mm thick.

The direct easterly descent of the huge valley of the Mai Shaha, down the Abbamarkos Wenz, is over amygdaloidal basalts in which the large amygdales are composed of agate, semi-opal, and beautiful specimens of fibrous and other zeolites, some coloured brilliant blue or green; some of these amygdales reach a diameter of more than 15cms. Some intercalated tuffs occur between the lavas, whilst there are notable N.E.-S.W. dyke swarms and also some sills dipping gently to the east. About 300m. above the Mai Shaha on the western side, ancient faulting of the lava series, no longer expressed topographically, is associated with severe slickensiding; the direction of downthrow may be to the east but this is uncertain.

On ascending the Dejen range from the Mai Shaha (2900m.) exposures of an extraordinary variety of basaltic lavas are crossed, especially between the Dejen col (4370m.) and the summit. However, the zeolite-rich basalts of the Buahit range are not significantly represented. Some vertical N.-S. dykes, especially common near the Mai Shaha, frequently reveal a more silicic composition than the lavas they cut, though basaltic dykes do occur.

The path over the 'Pass of Degien' is shown on Scott's map as passing north of the highest summit (Ras) Dejen itself. This would seem to be an error perhaps derived from the very poor lay-out of place-names on the British War Office 1:500,000 map, as in fact the col lies to the south of the summit, the path descending eastwards from the col down a broad, gently sloping valley which Nilsson (1940) describes as a cirque (see below). The map of Minucci (1938) is also in error regarding the Dejen massif, the orientation and positions of the highest peaks being confused: thus the spot-heights marked 4610 and 4585 should both be placed east of the main summit, and spot-height 4520 in fact lies south of (Ras) Dejen separated by the col which the path crosses in an almost precise E.W. direction (actually slightly S. of E.-N. of W.)

The summit of Dejen (4620m) is formed of holocrystalline trachybasalt lying above (upon?) extremely vesicular, almost cindery, reddish basalt which can be observed to rest upon light-grey, extraordinarily fissile trachyte. Porphyritic zeolitic basalts form the col, where a notable 1½m basaltic dyke trending N-S occurs. From Dejen the northern mountains of Simien: Kiddis Arit, Abba Yared, Silki, and Beroch Waha, are seen to be cut profusely by N-S dykes whose parallelism to the Mai Shaha valley is very evident. The lavas of the Dejen range dip at about 4° to the east, slightly steeper than the southward dip of the Buahit range stratoids. As with Buahit, the precipitous side of Dejen overlooks the Mai Shaha valley.

Upon the western spur which descends from the Dejen summit itself are preserved remnants of a vesicular, reddish basalt flow of relatively fresh appearance. The highest of the disconnected remnants lies at about 4150m., though it is possible that the red cindery basalt of the summit peak belongs to the same formation. It is evident that the vesicular basalt flowed in a very viscous condition, consolidating in a single thick, contorted tongue. In following the topographical profile of the spur, and thus cutting unconformably across the denuded sub-horizontal traps, it proves the lava to be of a much more recent date than the main series (see below).

3. GENERAL INTERPRETATION OF THE GEOLOGY OF SIMIEN

The regrettable fact exists that not only has no planned geological survey of Simien yet been made, but that even an extensive reconnaissance of the geology of the region is still awaited. This is more especially true of the northern peaks which from the geological standpoint form the most important part of the Simien massif, representing as they do the centre of the ancient volcano.

A study of the regional dips of the lava flows of Simien confirms the hypothesis of Nilsson (1940) that the Simien volcanic centre lay in the present-day region of the Abba Yared, Selki, and Beroch Waha peaks. Indeed, these mountains

are not composed of the usual sub-horizontal basalt flows but of thick massive tuffs and basaltic sheet intrusives. Whether the crater was as wide as 10km., Nilsson's estimate, must be uncertain considering the degree of denudation of the original cone and the lack of accurate data on stratoidal dips in the region north and east of Abba Yared where denudation has been most severe. The presence of steep northerly dipping lavas on the lower south slopes of Abba Yared seems to indicate original marginal crater subsidence. It is reasonable upon the evidence to presume that the ancient Simien volcano had an Hawaiian-type profile, with a fairly wide and shallow crater, and very extensive, gently sloping flanks to the cone. The periphery of the original cone has now been deeply cut into by river erosion, the huge thickness, durability, and massive character of the lavas causing the formation of gigantic vertical or near-vertical precipices on the north-west side of Simien, along the bounds of the extraordinary rock-tower, rock-spire and geometrically-shaped peaks of the Tzellemt country to the north, and along the eastern flanks overlooking the upper Tekeze valley. These precipices are frequently 1000-1500m. high. Beyond these precipices the stratoidal dips are still preserved, however, in the exposed basal lavas of the valley floors, proving the original cone to have covered an area of at least 15,000sq.kms.

The very varied petrography of the Simien lavas, despite their monotonously regular superposition, does not disguise the general fact that the Simien volcanic centre was one of a volatile-rich basaltic magma which was crystallising during ascent, in marked contrast to the hot, extremely fluid fissure basalts of the lower part of the Trap Series. The Simien magma was slightly more silicic than for the fissure olivine-basalts; a detailed study of the feldspars, both as phenocrysts and in the groundmass, is an urgent requirement for any future geological research in Simien. The tenuous evidence so far gathered suggests that the last eruptions of the Simien volcano were more silicic that the earlier ones.

The total thickness of the lavas of central Simien is calculated to be nearly 3000m., resting upon Mesozoic sandstones which in turn rest upon the Basement Complex. The base of the Trap Series lies conformably at approximately 1500m. elevation upon thick massive sandstones in the Tekeze valley to the east of Simien, but to the west at Galabat the Trap Series-Sandstone junction lies at a little below 1000m.. This difference in elevation may represent post-volcanic tilting down to the west, but is more probably an effect of the post-Mesozoic, pre-Trappean uplift of the Arabo-Ethiopian swell (Mohr 1962). It may be noted that the author was unable to confirm the existence of the "rough gritty rock" described by Scott from the bottom of the Mai Shaha valley, and which Scott implies to be Adigrat Sandstone. A consideration of the elevation of the Mai Shaha ford, 2900m., immediately reveals the unlikelihood of such a sandstone exposure unless unsuspectedly severe faulting has occurred. In fact, the author observed the Mai Shaha to have cut its present bed into highly porphyritic basalts, the corroded feldspar phenocrysts attaining 5cm. in length.

Regarding the sandstone formation upon which the Simien volcanics lie, this may be a marginal facies representing the conjunction of the Adigrat and Upper Sandstones of Tigrai, deposited along the margin of the maximum extent of the Jurassic sea, or, as in southern Gojjam and northern Wollega, the Adigrat Sandstone proper. The westerly dip of the Mesozoic strata in Beghemeder points to the former conclusion, thereby paralleling the Eritrean Sandstone formation in northern Tigrai and southern Eritrea, whose age, late Middle Jurassic, it probably shares. It is of interest that on an aircraft flight the author was unable to detect the presence of the Antalo Limestone formation along the western side of the Tekeze valley on the east slopes of Simien, and presumably the limestone was never deposited here*. In the southern regions of the Abbai basin the Antalo Limestone occurs as far west as 37.43 E.

The age of the Simien volcanics has been widely estimated between the Cretaceous (Nilsson 1940) and the post-Pliocene (Minucci 1938). The latter author bases his determination upon a fossil fauna obtained from a sedimentary intercalation in the Trap Series found at Ataba in northern Simien at an elevation of 1600m.. On the basis of this rather indeterminate terrestrial gastropod fauna, whose occurrence <u>within</u> the Trap Series needs confirmation, Minucci divides the lavas of Simien into the Ashangi Series below and the Magdala Series above. The author has elsewhere discussed the merits and de-merits justifying this sub-

*Furthermore, the author noted an unrecorded basin structure in the Trap Series at approx. 13.25°N, 38.55°E. Here, with a dip of 30° at the circumference the atratoid lavas have apparently subsided to form a remarkable 10kms. diameter basin. The margin od this circular area is sharply defined.

division of the Ethiopian Trap Series. Suffice it here to state that Minucci's subdivision is not warranted upon this meagre evidence; firstly, the presence of an unconformity is not proven (though a major unconformity is known within the Trap Series of western Gojjam); secondly the 'Magdala Series' of Simien is not, as the definition of Blanford requires, largely of silicic composition, but the whole massif is of predominantly basaltic composition, and with lava greatly exceeding pyroclastics in abundance except at the original volcanic centre.

There is therefore no strict evidence at present available to warrant attributing to the Simien volcano any age different from the rest of the Trap Series in northern Ethiopia, that is, Oligocene for the basal stratoid olivine basalts, possibly extending into the early Miocene for the final building up and activity of the main cone. The extent of denudation certainly precludes such a late date as post-Pliocene; even the Pliocene hyperalkaline silicic and carbonatitic centres of the margins of the Ethiopian Rift System have maintained traces of their original crater depression and walls.

The discovery of a much more recent lava-flow than the subhorizontal Trap Series upon the western spur of (Ras) Dejen parallels the discovery by Jepson (1960) of numerous such small extrusions in the Abbai basin, besides the well-known flows south of Lake Tana to which this lake owes its origin and existence. The date of these more recent lavas belonging to the Aden Volcanic Series, is considered, from their slightly denuded aspect and, in the Rift System, from their relationship to Pluvial sediments, to be of late Pliocene-early Pleistocene age.

The presence of large-scale faulting in Simien is also a new discovery*. The faults run parallel to the numerous dykes of the massif (especially numerous in the vicinity of the original centre) in directions between N.-S. and N.E.-S.W. Regarding the dykes, however, a more detailed survey might reveal a radiating pattern from the original volcanic centre. The minor faulting of the L. Tana basin also trends in the same general N.-S. to N.E.-S.W. direction, which coincides with and is undoubtedly related to the East African Rift System trend. Faulting in the Mai Shaha valley suggests that the straight N.-S. alignment of

*The attribution of the precipices of Simien to faulting in Lusana (1938a) is incorrect. However, the suggestion that the Ataba canyon is aligned along an old fault is not improbable.

this topographic feature has been tectonically determined; the presence of slickensiding with this faulting, however, allows of no easy explanation, as the Miocene faulting of Afar is not associated with thrusts or crush-faulting. Tectonic trends on the Ethiopian Plateau between N.-S. and N.E.-S.W. have been noted by the author in the Chokay Mts of Gojjam (alignment of subsidiary volcanic centres), in the faulting of the upper Abbai basin (Jepson 1960), and in the E. downthrown fault upon which Amba Bircutan is situated (in the lower Tekeze valley).

4. NOTES ON THE QUATERNARY GLACIATION OF SIMIEN.

An excellent summary discussion of the Quaternary glaciation of Simien is given by Scott (1958 pp. 11-13), of considerably more value than the discussion in the same paper on the solid geology which accepts too uncritically the assumptions and hypotheses of Nilsson. Regarding the present author's observations on evidence of former glaciation on Simien, these are too restricted in areal distribution to warrant a new discussion and theoretical presentation of the subject; the data collected can however be briefly stated.

Well preserved terminal moraines are seen above the source of the Serecava river on the west slopes of Buahit at an elevation of about 4100m.. As expected, no morainic material occurs on the steep eastern slopes of Buahit. No evident moraines were found on the western slopes of Dejen, despite the data of Minucci's map, but doubtful ones were observed below the col on the eastern side which Nilsson considers to be a cirque. There can be no doubt that any Pleistocene moraines on Simien have since suffered severely from the effects of Pluvial and fluvial erosion. However, a search for moraines on Abba Yared and Beroch Waha, both mountains whose summits lie little below that of Dejen, should be fruitful.

The evidence for cirques is similarly obscure and tenuous, and it would seem that the 'eye of faith' has been active with some previous workers. The source of the Serecava certainly lies in a glaciated valley, but in the opinion of the author there are no other convincing cirques on Buahit. Possible small cirques lie below Dejen, both to east and west, but are not so certainly glacial in origin as Nilsson (1940) suggests. Large cirques appear to be present on the northern peaks, with a definite case, worthy of considerably more attention, of a huge scooped out hollow rising southwards to a lintel at its exit, existing as the dividing valley between Beroch Waha and Selki.

The nature of the Mai Shaha valley is the most important contention in the theories of Minucci (1938) and Nilsson (1940) regarding the extent of Pleistocene glacition in Simien. Nilsson, supported by Scott (1958), considers the Mai Shaha valley to be of glacial origin, whereas Minucci does not. One of the most notable features of the Mai Shaha valley, apart from its great depth when compared with the present small stream flowing along its bottom, is the occurrence of southwards-dipping structural terraces (away from the old volcanic centre). No deposits occur upon these terraces, but their very existence is unfavourable to the glacial hypothesis where structural features are usually obliterated by the powerful force of glacial erosion. The Mai Shaha valley does not have the glaciated U-shaped profile. The morainic deposits reported by Scott (1958, p. 13 and Plate 1.) do not convince the author, to whom they better represent the results of heavy rain scree and earth slumping.

From a very brief acquaintance with the region, therefore, it is suggested that Minucci (1938) is correct in considering the Mai Shaha valley to have been excavated by powerful glaciofluvial and pluvial-accumulate river action during the Pleistocene Pluvials, erosion following an original line of tectonic weakness, and successively revealing structural terraces.

The almost total lack of scree at present being derived from the gigantic peripheral precipices of Simien points to their erosion having been almost entirely accomplished during the pluvial period.

5. WEATHER AND OTHER OBSERVATIONS*

No Quantitative temperature observations were made. However, at the Micheraguo, Deber and Serecava camps the early morning hoar frosts were of successively increasing severity. At the Serecava camp ice formed 1cm. thick on a pan of water. Subjective experience convincingly showed that at the time of year of the expedition, January, the upper western slopes of Buahit are colder than the eastern, whereas on Dejen the respective slopes seem to maintain a much more equal temperature. This was confirmed on the Buahit range by the relative levels down to which the streams were frozen in the early morning, and by the lower limit of the giant lobelia plants (3300m. on the Serecava slopes of Buahit; 4150m. on the

*For some useful observations on the meteorology of Simien,see Lusana (1938a & b).

Mai Shaha side). It would seem that the Mai Shaha valley acts as a sun-trap during the day and retains an appreciable amount of this heat during the night; the camp at 3250m on the east side of the Mai Shaha valley, as high as the Deber camp, was the only one where the expedition failed to experience the early morning hoarfrosts and freezing temperatures.

On the west side of Buahit permanent ice (January) lay in shaded hollows above 4200m, and frozen consolidated snow patches above 4250m, that is about 50m from below the col. Polygonal cracks characterised the disintegrated rock sand of the western slopes above 4100m. Lobelias were observed growing at elevations of up to 4400m on the west side of Buahit. On the eastern precipices of Buahit no permanent' ice or snow was observed, and the lower limit of lobelias was noted to be appreciably higher (4150m) than on the western side.

On the slopes below the western precipice of Dejen old snow patches were quite plentiful above 4200m, the higher patches being frozen extremely hard. Some lower patches, however, were soft enough for snowballs to be made; the very fine granular texture of these frozen deposits seems to preclude a hail origin, any recrystallisation normally tending to increase crystal size. A lobelia plant was found growing in a southern hollow only 10m below the summit of Dejen, that is at 4610m.

During the expedition a westerly wind prevailed, with convection cumulus showing a tendency to form more readily on the northern peaks than the others, and along the eastern edge of the Buahit range than on the Dejen range. Once formed, cloud tended to spread southwestwards. More cloud was formed on the Wolkait-Tzeghede range west of Simien than on Simien itself. Abuna Yosef to the south-east remained relatively free from cloud. No high cloud was observed during the expedition.

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AN OBLIQUE AZIMUTHAL EQUIDISTANT PROJECTION CENTERED ON ADDIS ABABA

MAX C. DE HENSELER*

In order to facilitate a rapid preliminary determination of earthquake epicenters using the data from a single station, an oblique azimuthal equidistant projection of the globe has been computed and is presented in Fig. 2. The projection is centered on the Geophysical Observatory in Addis Ababa whose geographic coordinates are North 09°02' and East 38°46'.

Assuming the globe to be a perfect sphere, the coordinates of each intersection on the grid were calculated as follows:

Given the spherical triangle N_pAB:

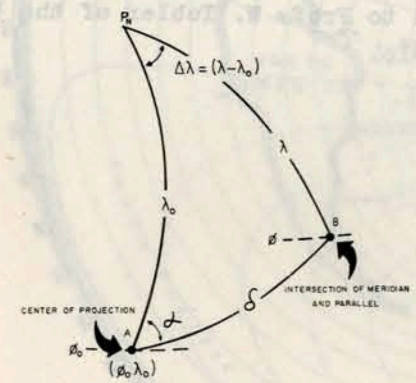

Figure 1

N_p = Geographic Pole.

A = Center of projection (station) of latitude (φ_o) and longitude (λ_o).

B = a point of intersection on the grid at latitude (φ) and longitude (λ).

we have:

$$\cos\delta = \sin\varphi_o \sin\varphi + \cos\varphi_o \cos\varphi \cos\Delta\lambda \quad (1)$$

$$\sin\alpha = \frac{\sin\Delta\lambda \cos\varphi}{\sin\delta} \quad (2)$$

in which:

α = angle between the meridian at center of projection (A) and the great circle passing through (A) and (B).

δ = angular distance between (A) and (B).

$\Delta\lambda$ = difference of longitude between (A) and (B).

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To simplify the construction of the map, the polar coordinates thus obtained were then converted into carthesian coordinates. No corrections for the ellipticity of the earth have been applied since such corrections would fall within the range of accuracy of the map.

A series of 703 grid points have been computed corresponding to a basic grid of 10 x 10 geographical degrees. Continents have been super imposed on the grid.

The original projection is 100cm in diameter; it has a radial scale of 1:4x10^7 and a reading accuracy, at the grid points, of better than 50km.

(Note: A copy of the original projection (41.5cm in diameter) is to be found in pocket attached to the back cover)

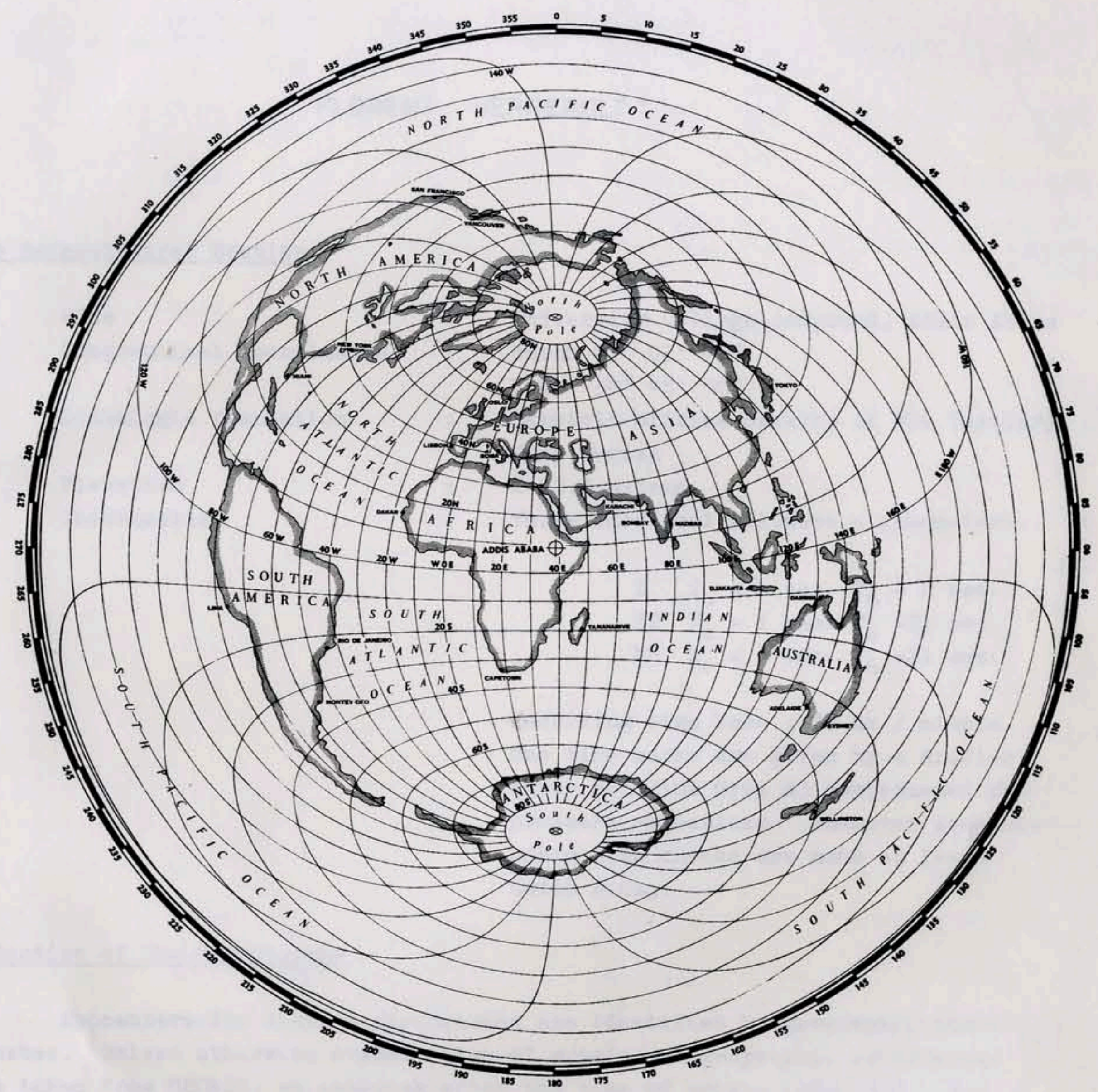
Acknowledgments:

The author expresses his sincerest thanks to Prof. W. Tobler of the University of Michigan U.S.A., for his advice and help.

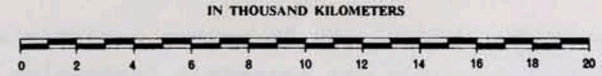
AZIMUTHAL EQUIDISTANT PROJECTION

CENTERED ON

ADDIS ABABA Lat. N. 9°01' 45", Long. E. 38° 45' 56"



SCALE ALONG ANY STRAIGHT LINE DRAWN FROM THE CENTER OF MAP IN THOUSAND KILOMETERS



DRAWN BY MAX C. DE HENSELER

SEISMOLOGICAL REPOR

(JULY-DECEMBER 1960)

FLORENT VERREAULT *

The Seismological Station

Site	:	University College compound, Addis Ababa
Geographical coordinates	:	North 09° 01' 45" East 38° 45' 56"
Lithologic foundation	:	Stratoid olivine basalts of the Tertiary Trap Series
Elevation	:	2442.5 meters
Instruments	:	Three identical Willmore seismometers:

Z T_o = 1 sec. T_6 = 2 sec.
EW T_o = 1 sec. T_6 =21 sec.
NS T_o = 1 sec. T_6 =21 sec.

- Recording time base : 30 mm / minute
- The time marks are given by a Riefler invar pendulum Type A3 compensated for pressure variations. Whenever possible radio time checks are made at least twice a day.

Reduction of the Seismograms

Epicenters for distant earthquakes are identified by geographic coordinates. Unless otherwise stated, time of origin and geographic coordinates are taken from USC&GS; an asterisk after the time of origin indicates a value given by BCIS.

For nearby quakes within a radius of abt. 1000km, whenever records permit, the approximate epicentral distances are given in kilometers; when the identification of the phases is doubtful, the qualification "local" is used.

*Institut de Physique du Globe, Paris.

		N TIME U.T.	PHASES		Lat.	Long.	EPICENTER h (km)	d° (km)	Location & Remarks
337	1 / 7		e	00-09-01					
338	1 / 7		e	12-30-13					Local
			i	-48					
339	1 / 7		i	20-56-21					Local
			i	-34					
340	2 / 7		e	04-40-48					
			i	42-22					
341	2 / 7		i	06-28-36					Local
342	2 / 7	11-55-41	iP	12-08-21	56S	27W			Sandwich Is.
343	3 / 7		iPg	06-24-01				330	
			Sg	25-02					
344	3 / 7	20-20-46	ePKP	20-39-05	50½N	177W			Andreanof Is.
			PP	40-25					
			ScS	47-30					
345	3 / 7		i	21-57-08					Local
			i	58-11					
346	4 / 7		e	03-48-51					
347	4 / 7	04-28-33	ePP	04-48-49	52N	131½W			Queen Charlotte Is.
348	4 / 7		iP	12-39-53				210	
			eS	-40-18					
349	6 / 7	05-16-44*	iP	05-24-05	36½N	70½E	200		Hindu Kush
			i(PP)	-25-39					
			i	-25-54					
350	6 / 7		eP	17-55-00				170	
			iS	-20					
351	6 / 7		e	21-07-21					
			i	-07-31					
352	6 / 7		e	23-03-25					
			i	-04-39					
353	6 / 7		e	23-43-42					
			i	-44-07					
354	7 / 7		iP	12-07-30				580	
			iS	-08-39					
355	7 / 7		e	23-04-30					
			i	-49					
356	8 / 7		i	08-35-34					
357	8 / 7		i	14-58-06					
358	8 / 7		iP	15-26-07				160	
			iS	-26-26					
359	8 / 7		iP	15-30-16				160	
			iS	-35					
360	8 / 7		iP	18-37-49					
			e(S)	-41-06					
361	8 / 7		i	21-02-43					
362	8 / 7		e	22-52-47					
			e	-53-36					
363	8 / 7		e	23-59-06					
			i	-36					
364	8 / 7		eP	07-10-45				200	
			iS	-11-09					
365	9 / 7		eP	10-58-52				170	
			iS	-59-12					
366	10/ 7	00-05-18*	iP	00-15-30	0	98E			Off West Coast of Sumatra
			iS	-23-44					
			Q	-32					
			R	-36					
367	10/ 7		i	08-27-21					
368	10/ 7	13-39-55*	iP	13-54-29	12½N	86W	150		Near Coast of Nicaragua
									Felt: Managua
369	10/ 7		iP	20-27-32				150	
			iS	-50					
370	11/ 7	11-55-10*	ePKP	12-15-01	16S	172W			Tonga Islands Region M =
			ePP	-18-36					
371	12/ 7		i(P)	02-29-56				185	
			i(S)	-18					
372	12/ 7		iP	02-40-29				210	
			eS	-54					
373	12/ 7		iP	03-33-05				185	
			iS	-27					
374	13/ 7		i(P)	06-12-10				170	
			i(S)	-30					

No.	Date	ORIGIN TIME U.T.	PHASES		Lat.	Long.	EPICENTER h (km)	d° (km).	Location & Remarks
375	13/ 7	07-55-54*	eP	08-07-25	53½S	1½E			Bouvet Is. Region M = 6
			(Q)	-29					
			(R)	-32-30					
376	13/ 7	13-01-00*	eP	13-07-53	41N	23½E			Greece. Minor damage on
			(S)	-13-34					Chalcidice Peninsula
377	14/ 7	10-26-58*	iP	10-39-56	5N	127½E			Molucca passage
			e(PP)	-43-32					
			e(PPP)	-45-26					
			eS	-50-28					
378	14/ 7	18-39-34*	iP	18-40-05	7N	38½E		200	Ethiopia M = 6.3
379	14/ 7		eP	20-34-37				190	
			iS	-59					
380	14/ 7		e(P)	20-51-49					
			e(S)	-52-15					
381	14/ 7		i	22-54-49					
382	15/ 7	01-07-16	i(P)	01-13-20	14S	22E			Angola - Rhodesia M = 5.9
383	15/ 7		iP	03-51-41				210	
			eS	-52-06					
384	15/ 7	05-02-05*	iP	05-07-05	12S	45½E			Off NW Coast of Madagascar
			eS	-11-15					
			R	-14					
385	15/ 7		iP	11-59-13				185	
			iS	-35					
386	16/ 7		iP	00-16-57				200	
			eS	-17-21					
387	16/ 7		iP	14-35-57				160	Ethiopia.BCIS gives repor
			eS	-36-16					from 8 other stations
			M	-37-10					
388	17/ 7	19-42-38*	(Q)	20-09	10S	13W			Ascension Is.
			(R)	-12					
389	18/ 7		iP	08-03-09				185	
			iS	-31					
390	18/ 7	18-50-32*	iP	18-55-18	7S	51½E			Amiraute Is.
			e(S)	-59-15					
			R	19-02					
391	18/ 7		i	19-36-56					
392	18/ 7			23-32-32				210	
				-57					
393	18/ 7		iP	23-40-42				200	
			eS	-41-06					
394	19/ 7		iP	03-22-45				200	
			iS	-23-09					
395	19/ 7		eP	23-08-26				195	
			eS	-49					
396	20/ 7		iP	16-35-50				195	
			iS	-36-13					
397	20/ 7	20-59-25	e	21-19-30	20½S	169E	200		New Hebrides
			R	22-09					
398	20/ 7	21-38-23	R	22-39	38S	73½W			Southern Chili M = 6
399	21/ 7		e	01-00-30				550?	
			i	-01-36					
400	22/ 7		iP	04-30-38				185	
			iS	-50					
401	23/ 7		iP	04-00-59				185	
			iS	-01-21					
402	23/ 7		iP	04-14-02				195	
			iS	-25					
403	25/ 7	03-41-05	eS	04-05-46	55N	163E			Near Coast of Kamchatka
			eSS	-13-45					M = 6
			R	-36					
404	25/ 7	11-12-00*	iP	11-25-39	54N	159E	100		Kamchatka M = 7
			iPP	-29-46					
			eS	-36-11					
405	25/ 7		iP	19-00-15				185	
			iS	-37					
406	25/ 7	21-11-36*	eP	21-17-34	32N	56½E			Iran
			R	-29					
407	25/ 7		iP	22-25-46				195	
			iS	-26-09					
408	26/ 7	12-36-20*	iP	12-42-41	40½N	37E			Turkey
				54-00					
409	27/ 7	10-04-53	R	11-03	44.7S	75.1W	25		Near Coast of Chile
									M = 6¼

No.	Date	ORIGIN TIME U.T.	PHASES		Lat.	Long.	EPICENTER h (km)	d° (km)	Location & Remarks
410	28/ 7		iP	07-14-30				185	
			eS	-52					
411	29/ 7	00-24-06	iPKP	00-43-29	19½S	170½S			Loyalty Is. M = 6½
			iPP	-45-50					
			R	01-34					
412	31/ 7	02-55-46	e(PKP)	03-13-07	5.6S	150.0E	25		New Britain M = 6½
			R	-54					
413	31/ 7		iP	15-51-19				210	
			iS	-44					
414	31/ 7	22-27-010	iP	22-32-10	27.9N	54.6E	127		Southern Iran
			e(S)	-36-37					
			R	-40.5					
415	1/ 8	02-20-524	iP	02-26-01	27.9N	54.2E	110		Southern Iran
			eS	-30-28					
416	2/ 8	05-07-221	iPKP	05-26-33	22.2S	171.5E	108		Loyalty Is. M = 6½
			i(SKP)	-29-54					
			e(SS)	-46-40					
417	3/ 8		e	23-09-40					
418	4/ 8	07-34-54	e(PKP)	07-53-00	51.4N	179.1E	83		Aleutian Is. M = 6¼
			R	08-34					
419	8/ 8	12-28-10	iP	12-29-46	12.0N	44E		660	Gulf of Aden M = 5½
			i	-30-28					
			i	-31-30					
420	8/ 8		e	13-18-30					
421	8/ 8		e	14-12-39					
			i	-57					
422	8/ 8	20-36-28	iP	20-42-15	36.0N	27.3E	87		Dodecanese Is.
423	9/ 8	16-46-377	iPKP	17-06-07	24.5S	177.1W	186		Tonga Is. M = 6¼
			R	18-02					
424	11/ 8	02-53-163	iP	03-06-01	0.0	126.1E	60		Celebes
			ePP	-09-11					
425	11/ 8	04-50-339	iP	05-03-12	8.8N	126.1E	79		Mindanao, Philippines
426	12/ 8		i	09-50-12					
427	12/ 8	13-12-343	iP	13-25-53	36.1N	141.4E	95		Near East Coast of Honshu
428	12/ 8		i	13-52-42				280?	
				-53-15					
429	13/ 8	07-11-055	iP	07-24-23	40.6N	142.0E	60		Near East Coast of Honshu
			iPP	-28-10					
			eS	-35-24					
			(R)	08-08					
430	13/ 8	14-14-577	e(PP)	14-34-22	39.7S	74.8W	61		Near Coast of S. Chile
			(S)	-44-00					
			Q	15-05					
			R	-11					
431	13/ 8		e	20-05-59					Could be 2 different shocks
			e	-08-24					
432	13/ 8	22-28-25	i	22-29-55	15.8N	40.2E	42	800	Off Coast of Eritrea
433	15/ 8	06-58-564	iP	07-06-04	13.4S	65.8E	15		Indian Ocean
			e(PP)	-07-12					
			eS	-11-38					
			R	-17					
434	15/ 8	14-33-384	eS	14-46-19	13.5S	67.0E	25		Indian Ocean
435	16/ 8	07-529	e	08-01-27					Congo M = 4.1
436	17/ 8	09-33-491	R	10-08	20.1S	11.4W	87		South Atlantic
437	17/ 8	11-24-072	R	11-53	19.8S	12.2W	25		South Atlantic
438	19/ 8		i	13-36-22					
439	20/ 8		i	14-03-13					
			i	-23					
			i	-36					
440	20/ 8		e	14-08-55					
441	20/ 8	20-08-390	R	20-42	35.6S	15.4W	37		Tristan da Cunha
442	20/ 8	21-19-527	R	21-53	35.3S	15.7W	36		Tristan da Cunha
443	20/ 8	22-22-446	eS	22-45-30	0.5N	122.0E	59		Northern Celebes
444	21/ 8	12-49-376	iP	13-02-00	4.9N	125.1E	211		Near Coast of Mindanao
445	23/ 8		e	02-13-42					
446	23/ 8		i	02-20-11					
447	23/ 8		iP	04-32-00	13N	52E			Socotra Region
			(R)	-38					
448	23/ 8		iP	06-31-06				335?	
			e(S)	-50					
449	23/ 8	08-58-121	iP	09-04-02	29.0N	59.9E	116		Southeastern Iran
			eS	-09-06					
			R	-14					
450	23/ 8		i	13-50-17					
451	23/ 8	14-08-149	iP	14-19-15	0.9N	26.0W	25		Atlantic Ocean
			(Q)	-42					
452	23/ 8	22-44-515	iPKP	23-04-37	14.5S	176.4W	56		Fiji Is. M = 6
			(R)	24-04					
453	24/ 8	01-44-099	Q	02-25	56.3N	163.8E	25		Near East Coast of Kamchatka
			R	-41					
454	24/ 8	05-49-01	R	07-07	19.0S	174.1W	42		Tonga Is.
455	24/ 8	19-27-53	eP	19-37-35	24.4N	95.0E	145		Burma - India Border
456	25/ 8	17-41-588	R	18-49	52.7N	169.6W	38		Aleutian Is.
457	25/ 8	23-02-26	R	24-04	37.8S	73.5W	109		Near Coast of Chile
458	26/ 8	00-14-05	R	01-16	37.8S	73.2W	25		Near Coast of Chile
459	26/ 8	18-27-182	iPKP	18-46-25	13.5S	165.9E	56		New Hebrides
			R	19-44					
460	27/ 8	10-17-181	iP	10-23-10	34.4N	26.3E	40		Crete
461	27/ 8		iP	18-06-48				200	
			eS	-07-12					
462	27/ 8		e	18-21-57					
463	29/ 8	18-00-352	e(P)	18-06-19	35.4N	27.1E	14		Crete
464	30/ 8	06-45-164	(PKP)	07-05-13	20.9S	113.7W	40		South Pacific
			(Q)	08-06					
465	30/ 8		iP	09-13-07				570?	
			i(S)	-14-15					
466	31/ 8	07-16-104	ePKP	07-36-33	20.9S	114.1W	25		South Pacific
467	31/ 8	17-21-551	e(P)	17-33-07	13.7N	120.1E	22		Near Coast Mindanao
468	31/ 8	22-11-54	iP	22-18-08	39.1N	36.3E	44		Turkey
469	2/ 9		iP	10-04-48				510	
			iS	05-49					
470	2/ 9	10-52-182	iPKP	11-11-18	15.2S	167.4E	163		New Hebrides
471	2/ 9	13-46-10	eP	13-56-07	28.7N	98.3E	48		Tibet
			R	14-23-30					
472	2/ 9	22-02-489	e(PKP)	22-21-49	52.0N	171.4W	49		Aleutian Is. M = 6
			e(PP)	-22-23					
			R	23-08					
			(R_2)	24-08					
473	2/ 9		e	23-03-15					
475	3/ 9	00-004	iP	00-06-35	38½N	42E			Turkey
476	3/ 9	05-41-399	iPKP	06-01-19	20.9S	174.4W	61		Tonga Is.
477	3/ 9	12-41-35	iPKP	12-59-37	6.1S	154.5E	457		Solomon Is. M = 6½-6¼
			eSS	13-16					
478	3/ 9		i	15-45-29					
479	3/ 9	23-46-239	eP	24-00-07	44.6N	149.1E	27		Kurile Is.
			ePP	-04-08					
			eS	-10-44					
			R	-41					
480	7/ 9	01-17-391	iP	01-28-45	37.2S	16.1W	25		Tristan da Cunha
			(Q)	-52					
481	7/ 9	03-51-52	iP	04-02-44	0	125.0E	68		Northern Celebes
482	7/ 9		e(P)	05-35-49					
			iS	-36-18					
483	8/ 9	11-07-408	eP	11-20-24	6.2N	126.2E	47		Near Mindanao
484	8/ 9		iP	12-06-31				700	
			iS	-07-54					
485	9/ 9	10-05-219	iP	10-12-46	36.4N	71.6E	236		Hindu Kush
486	10/ 9	00-19-084	iP	00-25-05	34.4N	26.4E	10		Crete
			R	-37					
487	10/ 9	10-44-512	iP	10-56-22	4.0N	122.6E	629		Celebes Sea
			eS	11-05-52					
488	10/ 9		e	16-07-40					
489	11/ 9		iP	12-10-45					Persian Gulf
			(R)	-15					
490	12/ 9	03-129	iP	03-15-45					Gulf of Aden
491	12/ 9		i	06-51-14					
			i	-29					
492	12/ 9	12-17-08	iP	12-29-50	27.3N	128.4E	48		Ryukyu Is.M = 6½
493	12/ 9	16-02-058	iP	16-13-20	7.0S	117.0E	611		Java Sea
			ipP	15-28					
494	12/ 9		iP	18-34-46				1000?	
			(R)	-37					

No.	Date	ORIGIN TIME U.T.	PHASES		Lat.	Long.	EPICENTER h (km)	d° (km)	Location & Remarks
495	13/ 9		eP	23-44-57				1000?	
			(R)	-47-30					
496	14/ 9	00-34-253	eP	00-46-46	16.9N	122.3E	50		Luzon, P. Is.
497	14/ 9		eP	18-27-08				1100	
			eS	-29-24					
			(R)	-29					
498	14/ 9	23-18-351	iPKP	23-38-22	20.9S	174.1W	25		Tonga Is.
499	15/ 9		iP	00-39-14				1100	
			(R)	-41-40					
500	16/ 9	01-183	iP	01-23-43	27½N	52½E			Persian Gulf
501	17/ 9	08-05-295	eP	08-19-18	49.4N	155.2E	28		Kurile Is. M =6
			eS	-30-22					
			R	09-04					
502	17/ 9	19-56-111	iPKP	20-15-55	20.9S	174.5W	28		Tonga Is. M = 6
			R	21-18					
503	18/ 9	09-40-28	iP	09-53-33	6.8S	129.2E	83		Banda Sea
			eS	10-04-00					
504	18/ 9		eP	23-46-44				640?	
			i(S)	-48-00					
505	19/ 9	03-39-41	eP	03-51-44	15.6N	120.0E	97		Luzon, P. Is.
506	19/ 9	19-01-25	e(SS)	19-37-10	6.9N	77.5W	66		Columbia-Panama border
			Q	-56					M = 6
			(R)	20-03					
507	21/ 9		i	03-25-30					Perhaps two local
			e	-42					shocks
			i	-45					
			i	-26-40					
508	21/ 9	16-08-147	iP	16-20-21	26.5N	124.8E	207		East China Sea
509	21/ 9	23-05-089	iP	23-10-33	31.9N	50.4E	84		Iran
			R	-20-30					
510	22/ 9	05-38-14	eP	05-41-56	3.4S	29.1E	29		Belgian Congo
			M	-46-30					Damage at Usumbura,
									and Uvira
511	22/ 9		(i)	08-53-23					Tremor lasting about
									7 minutes
512	22/ 9	09-05-368	iP	09-09-18	3.3S	29.3E	28		Belgian Congo M 6¼
			M	-14					
513	22/ 9	09-14-58	i(P)	09-18-54	2.8S	29.8E	20		Belgian Congo
514	22/ 9		i	15-17-55					
515	22/ 9		i	15-22-22					
516	23/ 9		i	23-10-14					Probably several
			e	14-32					local tremors
517	24/ 9	23-02-24	iPKP	23-22-05	22.2S	174.8W	39		Tonga Is. M = 5¼
518	24/ 9		e	22-14-46					
519	25/ 9		iP	02-44-03				530	
			iS	-45-06					
520	25/ 9		iP	07-16-35				700	
			iS	-17-57					
521	25/ 9	08-36-27	iP	08-41-31	28.2N	53.2E	53		Southern Iran
522	25/ 9	15-39-27	iPKP	15-59-06	17.3S	173.4W	132		Tonga Is.
523	26/ 9		e(P)	07-22-36					
			i(S)	-58					
524	26/ 9		e(S)	14-26-24					
525	26/ 9		e(S)	22-46-14					
526	28/ 9	17-34-588	ePKP	17-53-17	18.0S	178.8W	705		Fiji Is.
527	29/ 9	11-18-529	eP	11-32-05	18.9N	144.7E	469		Mariana Is. M = 6¼
			ePP	-36-27					
			e(SS)	-50-35					
			(G)	12-01					
528	30/ 9	01-38-419	iPKP	01-57-27	21.0S	174.6W	25		Tonga Is
529	1/10	03-00-50	e	03-10-48	23.3N	94.6E			Burma
530	1/10	08-251	e(S)	08-32-04	3S	29E			Congo M = 4.3
			R	-33					
531	1/10	16-10-57	ePKP	16-29-27	52.2N	172.6W	41		Aleutian Is. M = 6-6½
			R	17-14					
532	1/10		e	17-12-31					
			e	-13-36					
533	3/10	19-50-49	eP	20-01-45	05.7S	103.0E	51		Off Coast of Sumatra
			R	-27					
534	3/10		e	21-44-51					
535	4/10		e	09-29-03					
			e	-30-18					
536	4/10		e	13-53-20					
537	4/10		e	21-09-26					
538	4/10		i	23-11-28					
			e	-12-13					
539	5/10	01-58-54	i(P)	02-04-54	32¼N	56¼E			Iran
			R	-15					
540	7/10	15-18-308	eP	15-31-47	7.4S	130.7E	45		Banda Sea M = 6¼
			eS	-42-22					
			(R)	16-04					
541	7/10	20-01-326	iPKP	20-21-12	20.4S	113.7W	203		Easter Is. region
			(R)	21-20					M = 5¼
542	8/10	05-53-011	iP	06-04-40	40.0N	129.7E	608		Sea of Japan M = 6½
			ipP	-06-48					
543	8/10	20-40-066	eP	20-49-29	7.9N	92.9E	84		Nicobar Is.
			eS	-57-18					
			Q	21-04					
			R	21-07					
544	9/10		e	02-28-23					
545	9/10		i	06-03-12					
			e	-23					
			i	-36					
			i	-40					
546	9/10	09-00-42	eP	09-13-47	40.8N	141.2E	155		Near Honshu, Japan
			ePP	-17-33					M = 6
			eS	-24-18					
			R	-52					
547	9/10		i	10-10-59					
548	10/10		i	01-48-59					
549	11/10		e	12-31-21					
550	13/10	02-21-127	iP	02-28-33	45.2N	25.8E	63		Rumania
551	13/10		iP	10-18-37				280	
			iS	-19-10					
552	13/10	14-52-347	eP	15-06-25	54.8N	161.2E	35		Kamchatka M = 6½
			eS	-17-26					
			(G)	-31					
			R_1	-48					
			(R_2)	16-52					
553	14/10		eP	03-04-18				600	
			iS	-15-29					
554	14/10		e	10-36-25					
555	14/10	17-48-285	R	18-47	37.9S	74.7W	25		Off Coast of Chile
									M = 5¼
556	14/10	21-19-114	e(PKP)	21-37-52	51.7N	172.1W	50		Aleutian Is. M = 6½
			G	22-07					
			R	-20					
557	14/10	22-55-417	eP	23-07-16	55.5N	35.2W	40		North Atlantic
			(G)	-25					
558	16/10		e(P)	21-36-50					
			i	21-37-21					
559	17/10	15-45-369	i(PP)	16-05-31	4.8N	78.4W	83		Off Coast of Columbia
									M = 4¼
560	17/10	18-05-327	eP	18-17-26	30.7N	40.4W	65		Atlantic Ocean
561	17/10	19-02-21	eP	19-14-10	31.7N	40.7W	47		Atlantic Ocean
562	19/10		e	16-10-05					
			e	-52					
563	20/10	11-05-583	iPKP	11-25-05	11.0S	164.9S	40		Santa Cruz Is. M = 6
			R	12-22					
564	22/10	08-22-009	iPKP	08-40-50	10.3S	161.2E	93		Solomon Is. M = 6½
			R	09-28					
565	22/10		i	19-01-00					
566	23/10	06-32-25	iP	06-44-18	31.2N	40.7W	61		Atlantic Ocean
567	23/10		iP	09-33-10					
			e	-30					
			i	-44					
568	23/10		iP	18-53-10					Probably a foreshock
			eS	-55-20					of 569
			R	-57					
569	23/10	19-21-157	eP	19-23-25	17.9N	40.3E	25	1000	Red Sea
			eS	-25-43					
			R	-27					
570	23/10		eP	22-13-11					Aftershock of #569
			eS	-15-29					
			R	-17					

No.	Date	ORIGIN TIME U.T.	PHASES	TIME	Lat.	Long.	h (km)	d° (km)	Location & Remarks
571	23/10		iP	23-41-03					
			e	-23					
572	24/10		i(P)	04-02-05					Either replica of #569
			R	-06					or perhaps: BCIS 4¼S
									29E West of L. Tangan-
									yika 03-58-14
573	24/10	05-12-04	iPKP	05-31-05	15.0S	167.4E	145		New Hebrides
574	24/10		e	20-23-17					
			i	-24-02					
575	24/10		eP	19-47-52					
			i	-48-36					
			i	-44					
576	24/10		iP	17-37-02					
			e	-36					
577	25/10		e	12-28-18					
578	26/10		e	04-25-39					
579	26/10		i	16-27-30					
			i	-28-41					
580	26/10		i	21-22-37					
			i	-23-05					
581	27/10		i	02-05-39					
			i	-06-19					
582	27/10		i	02-26-15					
			i	-26-52					
583	27/10	22-27-551	iPKP	22-47-12	15.2S	175.0W	253		Samoa Is.
584	28/10	00-57.2	e	01-05-42					Congo
585	28/10	04-18-419	iP	04-29-51	71.3N	8.4W	48		Jan Mayen Is. M = 6
			(Q)	-50					
586	28/10	13-18-143	eP	13-31-52	52N	157.4E	96		Kamchatka
			eS	-42-26					
587	28/10		iP	18-44-13				185	
			eS	-35					
588	28/10		iP	18-50-06				200	
			iS	-30					
589	28/10	22-29-266	iP	22-42-40	34.4N	141.1E	96		Near Honshu
			iPP	22-46-38					
			eS	-53-26					
			R	23-22					
590	29/10	01-25-355	eP	01-32-30	25.5N	67.6E	23		West Pakistan
591	29/10	04-17-021	iP	04-29-32	15.4N	46.4W	38		North Atlantic
			(Q)	-56					
592	29/10	09-37-416	ePKP	09-57-23	15.8S	172.9W	99		Samoa Is. M = 5½
593	30/10		iP	10-29-07					
			i	-50					
594	30/10	12-14-361	ePP	12-33-53	23.3S	70.3W	76		Near Coast of Chile
			e(PS)	-43-25					M = 6¼
			R	13-14					
595	30/10	15-50-504	eS	16-14-19	1.0S	127.0E	32		Spice Is.
596	30/10	21-32-477	ePP	21-51-42	22.8S	68.0W	60		Chile - Bolivia bor-
			e(PS)	22-01-08					der M = 6¼
			R	-35					
597	31/10	12-275	e	12-36-16					Central Africa M = 4.3
598	31/10		iP	19-07-33				125	
			iS	-48					
599	31/10		i	23-04-07					
			i	-45					
600	1/11	06-15-294	iP	06-25-07	11.1S	12.7W	35		Ascension Is. Region
			Q	-42					M = 5
			R	-45-30					
601	1/11	08-46-019	ePP	09-04-22	38.4S	74.4W	97		Near Coast of Chile
			e(PS)	-15-30					M = 7
			Q	-36					
			R	-47					
602	1/11	12-29-316	R	13-30	38.5S	75.0W	64		Near Coast of Chile
603	1/11		e	12-56-54					M = 5
604	1/11		e	13-30-34					
605	2/11	16-31-535	eP	16-41-17	23.1N	93.8E	126		Burma - East Pakistan
606	2/11	17-14-493	iPKP	17-33-57	10.9S	164.9E	25		Santa Cruz Is.
			(Q)	18-22					
			R	-30					
607	2/11	18-09-488	eP	18-20-37	44.8S	80.2E	23		South Indian Ocean
608	2/11		e	18-26-17					
			i	-38					
609	3/11	02-42-545	ePKP	03-02-38	22.1S	175.1W	25		Tonga Is. M = 5½
610	4/11		i	06-27-52					
611	4/11	16-520	iP	16-57-05	27N	54E			Sud de l'Iran
612	5/11		iP	11-11-38					
			i(S)	-12-06				235	
613	5/11	20-20-537	iP	20-27-39	39.2N	20.5E	49		Near Coast of Greece
									M = 5
614	6/11	04-38-167	eP	04-52-05	53.0N	159.8E	32		Near East Coast of Kam-
			e(S)	05-02-51					Chatka M = 6
			G	-19					
			R	-33					
615	6/11	06-15-057	Q	07-27	31.0S	177.7W	184		Kermadec Is. Region M = 6
			R	-34					
616	6/11		e(P)	08-13-32					
				-44					
617	6/11		e	08-15-47					
				-16-00					
618	6/11	22-10-064	e(PS)	22-39-32	52.7N	168.0W	42		Fox Is. Aleutian Is.
			R	23-17					M = 5¼
619	6/11		e	24-03-00					
			(R)	-19					
620	7/11		i	13-29-28					
621	8/11	04-28-114	iP	04-40-24	27.8N	44.3W	25		North Atlantic
622	9/11	03-17-585	iP	03-30-38	60.7S	24.8W	37		Sandwich Is. M = 6¼
			iS	-41-08					
			Q	-58					
			R	04-04					
623	9/11	10-43-431	iP	10-54-17	32.7N	103.4E	47		Szechwan Prov., China
			i(PPPP)	-58-16					M = 6¼
			e	11-03-04					
624	9/11		eP	20-42-15					
			i	-43-07					
625	9/11	20-06-16	(R)	21-05	23.2S	70.6W	52		Near Coast of Chile
									M = 5½
626	10/11	01-54-47	iP	02-02-54	36.6N	71.1E	64		Hindu Kush
627	10/11	14-44-47	iP	14-58-40	2.6S	139.4E	25		New Guinea M = 6¼
			iS	15-10-08					
				-(48)					
628	11/11	05-31-34	iP	05-38-14	39.5N	21.1E	39		Greece - Albania
629	11/11	22-22-167	iP	22-32-02	6.5N	94.4E	25		Nicobar Is.
630	13/11	06-37-057	iP	06-49-56	1.4N	127.2E	59		Molucca Passage
			eS	07-00-17					
			Q	-16					
631	13/11	09-20-368	iPKP	09-39-04	51.1N	168.8W	65		Fox Is., Aleutian Is.
			ePP	-40-18					M = 7
			eSKS	-46-18					
			eSKKS	-47-32					
			ePS	-50-08					
			G	10-08					
			R	-23					
632	13/11		iP	15-56-27					
			i(S)	-57-22					
633	13/11	21-22-456	R	22-29	56.2S	122.6W	38		South Pacific
634	14/11		i	18-12-02					
635	14/11		e	22-19-39					
636	15/11		i	03-04-40					
637	15/11	06-23-275	ePKP	06-42-33	62.5S	161.7W	46		Antartic Ocean M 5½
			(R)	07-26					
638	15/11	09-05-59	i	09-15-38	23.2N	94.3E	103		Burma - India Border
639	15/11		e	20-45-06					
			i	-26					
640	16/11	01-23-111	iPKP	01-41-42	23.7S	179.3E	552		South of Fiji Is.
641	16/11		i	16-26-08					
642	16/11	22-59-476	iP	23-09-18	38.0S	89.5E	24		Sinkiang Prov., China
643	18/11		i	12-50-23					
644	18/11		e	15-08-27					
645	19/11		e	19-30-32					
646	21/11		iP	17-32-37					
			iS	-59				185	
647	22/11	03-03-027	i(P)	03-14-43	8.2N	38.4W	33		Atlantic Ocean
			R	03-41					

No.	Date	Origin Time U.T.	Phases		Lat.	Long.	h (km)	d* (km)	Location & Remarks
648	22/11	03-31-543	iPKP	03-51-42	19.2S	173.1W	25		Tonga Is.
			R	04-50					
649	22/11	03-45-208	iPKP	04-05-08	19.7S	172.6W	70		Tonga Is.
			(R)	05-08					
650	22/11	06-21-450	iP	06-30-20	35.9S	52.3E	21		Indian Ocean M = 6¼
			S	-37-16					
			R	-45					
651	22/11		e	10-10-52					
652	22/11	12-28-584	iPKP	12-47-33	40.0S	74.3W	107		Near Coast of S. Chile
			iPP	-48-27					M = 6
			ePS	-58-05					
			R	13-28					
653	22/11		i	14-03-16					
654	22/11	17-51-365	iP	18-01-16	7.3N	95.7E	25		Nicobar Is.
655	23/11		e	12-09-28					
			e	-42					
656	23/11	14-12-211	iPKP	14-32-00	24.2S	176.1W	28		South of Tonga Is.
			(R)	15-25					M = 7
657	23/11	16-52-129	iP	17-04-48	4.6N	125.8E	143		Near Mindanao, P. Is.
658	23/11	17-56-380	iPKP	18-16-12	24.0S	176.3W	51		South of Tonga Is.
659	24/11	04-50-158	iPKP	05-08-54	4.6S	153.0E	87		Near Britain Region
			eSKS	-15-43					M = 6¼
660	24/11	06-52-411	ePKP	07-12-16	24.2S	176.1W	23		South of Tonga Is.
			R	08-07					M = 7
661	24/11		iP	07-34-50					
662	24/11	08-16-437	iPKP	08-36-22	24.4S	176.3W	25		South of Tonga Is.
663	24/11	08-26-144	iPKP	08-45-52	24.5S	175.9W	25		South of Tonga Is.
664	24/11		e	11-33-48					
			e	-35-11					
665	25/11		e	11-01-15					
666	25/11		e	13-06-00					
			e	-07-24					
667	25/11		e	16-04-02					
			i	-05-40					
668	25/11		e	16-39-35					
669	25/11	21-54-138	iP	22-07-20	38.0N	140.5E	157		Honshu, Japan
			(PP)	-11-10					
			(S)	-17-52					
670	26/11		i	07-12-04					
671	27/11		i	15-02-24					
			i	-03-12					
672	27/11		i	18-01-02					
673	27/11	20-37-264	iP	20-41-03	3.1S	29.1E	60		Belgian Congo
674	27/11		i	21-27-00					
675	27/11	21-24-328	R	22-24	37.3S	72.5W	100		Near Coast of Chile M = 5¼
676	29/11	09-32-015	R	10-29	44.0S	74.9W	86		Near Coast of S. Chile M = 5¼
677	29/11		iP	14-19-35					
678	30/11		iP	01-38-00					
			(R)	-42-30					
679	30/11		i	11-57-03					
			i	-57-23					
680	1/12	04-02-372	i(P)	04-08-50	38.1N	30.6E	137		Western Turkey
681	1/12	08-42-265	iPKP	09-02-05	32.3S	113.1W	25		Eastern Is. Region
682	1/12	10-40-300	ePKP	10-60-05	24.4S	176.2W	25		Tonga Is.
			R	11-59					
683	1/12	20-49-455	R	21-58	48.8N	129.3W	15		Vancouver Is. M = 6
			(R_2)	22-56					
684	2/12	09-10-410	i(P)	09-25-24	24.5S	69.9W	37		Near Coast of Chile
			(PP)	-30-13					M = 7
			(Q)	10-00					
685	2/12	13-43-21	iP	13-47-06	3½S	29E			NW du Lac Tanganyika
			i(S)	-50-06					M = 5
686	2/12		e	18-40-39					
687	2/12	19-41-063	iP	19-52-09	41.6S	88.3E	35		South Indian Ocean
688	3/12	04-24-175	eP	04-35-07	42.8N	104.5E	45		Outer Mongolia M = 7
			eS	-43-58					
			R	05-00					
689	3/12		i	05-03-45					
690	3/12	07-07-427	i(PP)	07-26-46	52.5N	177.3W	79		Aleutian Is.
691	3/12	09-12-190	iP	09-24-30	21.1N	121.1E	35		Off S. Coast of Formosa
692	3/12	17-56-280	iP	18-07-20	43.1N	104.3E	25		Outer Mongolia
693	3/12	20-21-013	iP	20-33-25	76.7N	131.1E	28		Laptev Sea
694	3/12	22-16-00	iP	22-21-11	30N	52E			Sud de L'Iran
695	4/12	15-47-23	eP	15-59-41	1.1N	120.6E	46		Northern Celebes
696	4/12	23-55-393	iPKP	24-14-04	21.2S	179.0W	633		Fiji Is.
697	5/12	08-38-495	iP	08-49-36	43.0N	104.3E	59		Outer Mongolia
			R	09-18					
698	5/12	21-21-517	iP	21-30-35	35.7N	6.5W	66		Strait of Gibraltar
			(R)	-48					
699	6/12	03-35-306	iP	03-46-19	42.9N	104.5E	55		Outer Mongolia
700	6/12	08-56-165	i(PKP)	09-15-54	8.5N	82.7W	116		Near Panama M = 6
701	6/12	08-56-076	i(PP)	09-15-40	21.4S	69.0W	25		Northern Chile M = 5½
702			iP	14-04-27					
			iS	-05-29					
703	7/12	16-19-092	iP	16-31-15	1.2N	121.8E	40		Celebes Sea
704	7/12	17-365	iP	17-41-51	28N	56E			Southern Iran
705	7/12		i(S)	19-06-01					
706	8/12	01-24-189	iPKP	01-42-40	21.8S	179.4W	685		Fiji Is.
707	8/12		iP	19-24-53	9.8N	125.5E	77		Leyte, Philippine Is.
708	9/12	00-36-182	iPKP	00-55-44	20.4S	176.2W	137		Tonga Is.
709	10/12		e(S)	04-31-21					
710	10/12	13-32-183	iPKP	13-52-11	15.0S	172.3W	25		Samson Is. Region
711	10/12	13-55-165	eP	14-07-285	1.5N	124.3E	292		Celebes Sea
712	10/12		eP	21-38-525					
			i	39-410					
			S	39-455					
713	10/12		eP	21-46-150					
			i	47-050					
			S	47-095					
714	11/12	00-01-104	ePKP	00-20-18	22.1S	171.4E	144		Loyalty Is.
			iPP	-22-41					
			i	-23-38					
715	11/12	03-18-109	eP	03-31-04	1.6N	126.4E	52		Molucca Passage
			eS	-41-32					
716	11/12		i	12-23-36					
717	11/12	18-53-092	ePKP	19-12-125	15.7S	166.9E	133		New Hebrides Is M = 6½
			R	20-01					
718	12/12		e	01-01-55					
719	12/12		eP_1	07-41-56					
			S_1	42-36					
720	12/12		e	20-43-23					
721	13/12	07-36-138	e	07-56-48	52.1S	160.9E	29		Macquarie Is. M = 7
			e	08-12-36					
			(Q)	-32					
722	13/12	09-03-092	ePKP	09-22-41	21.8S	175.5W	84		Tonga Is.
723	13/12		iP	15-17-21				570	
			iS	-18-29					
724	13/12		e	18-57-25					
725	14/12		eP	00-31-27					
			iS	-32-08					
726	14/12	00-57-250	iPKP	01-16-31	10.8S	165.4E	65		Santa Cruz Is.
			R	02-07					
727	14/12		e	05-27-34					
728	14/12		iP	21-26-13					
			i	27-435					
729	14/12		e	22-09-17					
730	14/12		i(S)	23-08-35					
731	14/12	23-51-286	iP	24-04-12	2.9N	126.5E	77		Molucca Passage M = 6¼
			iS	-14-39					
			(R)	-34					
732	15/12		e	01-18-19					
733	15/12		e	03-38-45					
734	19/12		i	20-59-32					
			i	-48					
			i	21-01-07					
735	19/12		i	23-39-00					
			i	-40-23					
736	20/12		iP	02-28-33				710	
			i	-50					
			iS	-58					
737	20/12		i	09-22-43					
738	20/12		i	16-42-03					
			i	-43-23					

No.	Date	TIME U.T.	PHASES		EPICENTER Lat.	Long.	h (km)	d* (km)	Location & Remarks
739	21/12		i	07-54-44					
740	21/12		i	13-10-27					
741	21/12	14-40-016	iPP	14-58-48	61.6N	152.3W	169		Alaska M = 5¼
742	21/12	22-29-549	e(PP)	22-49-34	62.5S	167.1E	29		North of Balleny Is.
			R	23-36					
743	22/12	03-02-292	iP	03-11-52	9.8N	94.2E	60		Nicobar Is.
			eS	-19-37					
			(Q)	-27					
			(R)	-31					
744	22/12	06-31-215	iPKP	06-50-50	30.8S	177.1W	46		Kermadec Is.
745	22/12	14-12-187	iPKP	14-32-00	27.8S	176.1W	60		Kermadec Is.
			R	15-29					
746	22/12		e	16-04-49					
747	22/12	21-02-411	iPKP	21-20-41	6.8S	155.3E	469		Solomon Is. M = 5½
748	23/12		i	03-24-17					
749	23/12		e	03-55-02					
			i	-18					
750	23/12	09-41-484	iP	09-52-15	3.3S	101.9E	134		Near Sumatra
751	23/12	10-47-579	eP	11-00-43	8.2N	125.7E	67		Mindanao, Ph. Is.
			eS	-11-29					
752	23/12	19-30-416	iP	19-42-59	15.6N	121.7E	49		Near Luzon, Ph. Is.
753	24/12	03-55-337	eP	04-02-47	17.6S	66.6E	100		Indian Ocean
754	24/12		e	10-23-15					
755	24/12		i	19-00-28					
			e	-51					
756	26/12	00-56-166	ePKP	01-15-55	23.7S	176.9W	59		Tonga Is.
757	26/12	01-44-487	e(P)	01-57-52	33.8N	136.2E	109		Near Honshu, Japan
			i(PP)	02-01-38					
			eS	-08-52					
758	26/12	04-32-301	iP	04-45-07	57.4S	26.2W	25		Sandwich Is. M = 5¼
			eS	-55-37					
			(Q)	05-14					
759	27/12	10-35-280	R	11-48	41.3N	124.9W	30		Off Coast of N. Cal-
									fornia M = 5½
760	28/12	01-576	iPKP	02-16-09					Fiji Is., Very deep
761	28/12	02-19-15	iP	02-25-25	35N	22¼E			SW of Crete
762	28/12	05-39-437	iP	05-45-51	34.9N	22.5E	67		Near Coast of Greece
			(R)	-58					
763	29/12	06-02-139	iPKP	06-21-50	18.4S	174.7W	104		Tonga Is.
764	29/12	10-36-400	iPKP	10-55-17	44.8S	75.6W	30		Near Coast of S.
			Q	11-31					Chile M = 6
765	29/12	18-19-416	iP	18-25-46	35.3N	22.6E	54		Near Crete
			R	-38					
766	29/12	19-01-381	ePP	19-20-50	18.8S	69.4W	39		Northern Chile
767	30/12		i	01-07-21					
			i	-34					
			i	-08-49					
768	30/12		e	04-09-40					
769	30/12	05-29-286	iP	05-42-04	9.6S	121.0E	53		Sawoe Sea
770	30/12		e	18-11-26					
771	31/12		iP	00-50-05					
772	31/12	16-05-221	iP	16-17-56	7.8S	120.1E	25		Flores Sea
			eS	-28-14					
773	31/12		iP	16-20-55					
			i	-21-18					
774	31/12	18-08-123	e(PP)	18-27-40	43.9S	75.0W	92		Near Coast of S.
									Chile M = 6
			(R)	19-06					