No. 124 ARIZONA-NASA ATLAS OF INFRARED SOLAR SPECTRUM, REPORT II

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ABSTRACT

This paper is a continuation of *LPL Comm.* 123 covering the interval λλ 10657-12857 Å. The arrangement is the same as in Report I.

In the interest of prompt publication, we are here reproducing Charts 7–15 of the Infrared Solar Spectrum Atlas. *LPL Comm.* No. 123 covers the region λλ 8487–9725 Å, much of it recorded twice. The original observing plan called for a continuous record to the longer wavelengths, but the region λλ 9758–10657 Å, which contains no strong telluric lines and which had been very well recorded in the Liège *Atlas,* had to be omitted when a second run of the important λ 9000 Å region became necessary because of heliostat troubles. Chart 7 begins with two short sections that continue the two parallel records of Chart 6. Thereupon, an unbroken record with the 1200-line grating is available from λ 10657–λ 12857 Å, recorded in two parts that overlap from λλ 12244–12314 Å. A small second gap (about 300 Å) follows, whereupon the 1200-line record continues to about 14400 Å, through the heavy part of the 1.4 μ water-vapor band. (This gap, again, was not planned, but had to be accepted as the flight schedule evolved; both gaps were covered, however, with lower resolution.)

In addition, the 600-line-per-mm grating records start at 12188 Å and continue without break to λ 29000 Å, continued in turn with 300-line/mm grating coverage to about 33000 Å (cf. *LPL Comm.* No. 125).

The present report covers the interval λλ 10657–12857 Å with the 1200-line/mm grating. In this region precise wavelength calibrations did not present major problems. Up to λ 12016 the Liège *Atlas* could be used, supplemented by laboratory spectra of the 11350 Å water-vapor band and of the 12055 and 12206 Å CO_2 bands, roughly matching the intensities in our solar spectra. These laboratory spectra were kindly obtained by Dr. Uwe Fink and Mr. A. Thomson. Beyond the λ 12016 Å limit, the *Table of Solar Spectrum Wavelengths, 11984 Å–25578 Å* by O. C. Mohler (1955) was used almost exclusively.

Both sources proved invaluable also in the verification of some of the *weaker lines* shown on our spectra. Normally, duplicate records would have served that purpose, and some regions were indeed recorded twice. In general, the flight schedules did not permit this, however. (Before the final *Atlas* is issued, it is expected that new solar spectra will have become available taken on a very dry mountain.) The weakest lines recorded in the present solar spectra have about 0.005 Å equivalent width.

The *resolving power* may be tested on Chart 14 where narrow lines occur. The pair at λ 12648, $\Delta\lambda = 0.30$ Å, is well separated; the pair at λ 12621, $\Delta\lambda = 0.21$ Å, is seen as a pair; the pair at λ 12680, $\Delta\lambda = 0.15$ Å, is seen only as a blend. Hence $\Delta\lambda = 0.21$ Å is the limit of resolution; or $R \simeq 60{,}000$.

On Charts 7, 9, 10, and 15 five small regions occur (marked *g*) where the continuum was slightly depressed by minor guiding errors, noted at the time when the observations were made (due to drift of the solar image on the slit). On Chart 13 during a few brief moments overhead cirrus was noted, as indicated on the Chart, and apparently responsible for a few weak spurious absorptions.

The observing procedures have been described in *LPL Comm.* No. 123. The chart numbers used here, 7–15, continue from LPL 123 so that they can be retained in the final *Atlas*. The relevant data are listed in Table 1. The observations were made by the first two authors, assisted by Mr. A. Thomson and Rev. G. Sill. The wavelength scales were derived independently by Mr. Bijl and Dr. Kuiper. The laboratory H_2O records mentioned proved so useful in the identification work (because of the line intensities) that they are reproduced in the *Addendum*. Comparison charts of the Michigan *Atlas* are again included, to clarify the gains obtained at the 200-mb level; though the precision of the 1950 records has obviously been greatly improved upon in the unpublished traces used in O. C. Mohler's 1955 *Table* (which includes lines too weak to be seen in our spectra).

The comparisons with the ground-based records have shown some classifications in the Babcock-Moore catalogue (1947) to require revision. Since identification work on solar lines is proceeding, we are listing in Table 2 some of the stronger "solar" or "probably solar" lines from that catalogue that are absent from our spectra and are therefore telluric. On the other hand, strong solar (not "atmospheric") lines, not recorded before, are found at $\lambda\lambda$ 11018, 11130, 11188, 11197, 11251, 11253, 11255, 11290, 11299, 11330, 11486, and 11700 Å; and numerous weaker lines, as indicated by the dots on our charts.

On the bottom strip of Chart 8, very faint water-vapor lines have been indicated to assist comparisons with ground-based records. Normally, we have omitted reference to the telluric component of a blend *if its contribution is less than one-fourth of the equivalent width of the combined feature*. Exceptions are $\lambda\lambda$ 11127, 11134, and 11149, where the water-vapor contribution is less than one-fourth, but where its presence is nevertheless indicated above the spectrum to facilitate comparisons with the Liège *Atlas*. There is a question about λ 11276; it is possible that it is *all* due to H_2O (Dr. Kuhn of ESSA, who recorded the integrated water-vapor content of the atmosphere above the aircraft, reported changes during our observations).

In the Charts, we have identified telluric absorptions by symbols *above* the records: H_2O by *dots*, O_2 (1.07 μ, 1.25–1.28 μ) and CO_2 (1.20 and 1.22 μ) by lines. The identifications by element were taken from the Babcock-Moore catalogue, as before, and the Mohler *Table*.

After the August 2, 1968 solar observations had been completed, a comparison record was made of H_2O absorption in the spectrometer itself. The conditions were not entirely identical, since for safety reasons (brittle optical windows) the flight altitude had already been decreased from 41,500 ft to 35,000 ft and the cabin pressure changed from 9900 ft to 6900 ft. Both changes will have increased the H_2O intensities. Nevertheless, the absorptions in the λ 11300 band were negligible. *The water-vapor intensities in the solar Charts are therefore almost entirely (> 90%) due to the overlying atmosphere, not the cabin.* For CO_2 and O_2 the cabin contribution (path ~22 meters, p ~750 mb) is about 1 percent in the number of molecules and about the same in the absorptions (the lines being weak).

It is noted that the H_2O absorptions are *narrower* than those in the laboratory spectra in the Addendum, apparently because of the much lower atmospheric pressure (< 200 mb) and temperature (T ~ −54°C).

Acknowledgments. As before, we wish to record our indebtedness to NASA Hq. and NASA-Ames for their interest in the high-altitude program; to Messrs. J. Percy and B. McClendon for assistance with the electronics during the flights; to Mr. A. Thomson and Rev. G. Sill of LPL and Mr. D. Olsen of NASA-Ames for their important assistance during the flights in the solar guiding and the taking of spectral records. Mrs. A. Agnieray again assisted in the preparation of the figures for publication. This research was supported by NASA through Grant

TABLE 1

SOLAR SPECTRUM RECORDS, 4.2-METER SPECTROMETER, NASA CV-990 JET
1 μ GRATING (1200 LINES/MM), SLIT AND CELL 0.10 MM, τ = .12 SEC.

FIG.	CHART	λ (Å)	1968 DATE	UT	ALT. (FT)	TEMP. (°C)	CABIN ALT. (FT)	GAIN
1	7. a	9725– 9758	Aug 2, 6	19:18, 20:57	41,500	−57, −59	8900	5–3, 1
	b	10657–10731	Aug 2	19:27	41,500	−57	8900	5–3
	c	10731–10807	Aug 2	19:31	41,500	−57	8900	5–3
	d	10807–10880	Aug 2	19:34	41,500	−57	8900	5–3
2	8. a	10880–10955	Aug 2	19:38	41,500	−56	8900	5–3
	b	10955–11031	Aug 2	19:41	41,500	−56	8900	5–3
	c	11031–11104	Aug 2	19:45	41,500	−56	8900	5–3
	d	11104–11177	Aug 2	19:49	41,500	−56	8900	5–3
3	9. a	11177–11250	Aug 2	19:52	41,500	−54	9900	5–3
	b	11250–11321	Aug 2	19:55	41,500	−54	9900	5–3
	c	11321–11393	Aug 2	19:58	41,500	−52	9900	5–3
	d	11393–11467	Aug 2	20:01	41,500	−52	9900	5–3
4	10. a	11467–11539	Aug 2	20:04	41,500	−54	9900	5–3
	b	11539–11613	Aug 2	20:07	41,500	−54	9900	5–3
	c	11613–11686	Aug 2	20:11	41,500	−54	9900	5–3
	d	11686–11757	Aug 2	20:14	41,500	−54	9900	5–3
5	11. a	11757–11832	Aug 2	20:18	41,500	−54	9900	5–3
	b	11832–11904	Aug 2	20:21	41,500	−54	9900	5–3
	c	11904–11975	Aug 2	20:25	41,500	−54	9900	5–3
	d	11975–12047	Aug 2	20:28	41,500	−54	9900	5–3
6	12. a	12047–12114	Aug 2	20:31	41,500	−54	9900	5–3
	b	12114–12179	Aug 2	20:35	41,500	−54	9900	5–3
	c	12179–12247	Aug 2	20:39	41,500	−54	9900	5–3
	d	12247–12314	Aug 2	20:42	41,500	−54	9900	5–3
7	13. a	12244–12306	Aug 6	18:13	41,500	−58	8900	5–2
	b	12306–12369	Aug 6	18:16	41,500	−58	8900	5–2
	c	12369–12431	Aug 6	18:19	41,500	−58	8900	5–2
	d	12431–12494	Aug 6	18:22	41,500	−58	8900	5–2
8	14. a	12494–12556	Aug 6	18:25	41,500	−58	8900	5–2
	b	12556–12619	Aug 6	18:29	41,500	−58	8900	5–2
	c	12619–12678	Aug 6	18:32	41,500	−58	8900	5–2
	d	12678–12736	Aug 6	18:35	41,500	−58	8900	5–2
9	15. a	12736–12797	Aug 6	18:38	41,500	−58	8900	5–2
	b	12797–12857	Aug 6	18:41	41,500	−58	8900	5–2

TABLE 2

TELLURIC LINES PREVIOUSLY CLASSIFIED ⊙ OR ⊙?

λ	INT.	λ	INT.	λ	INT.	λ	INT.
10677.01	−1	11246.95	2	11569.96	0	11876.32	10 NN
10718.08	1	11278.21	−1	11605.31	7 *	11886.24	−2 N
10816.03	1 N	11280.03	0	11623.06	0 N	11897.22	−2 N
10858.36	−1	11285.05	0	11624.76	−1 N	11903.17	1 n
10890.13	−1	11364.08	−2 N	11630.50	1 N	11906.82	1 N
10909.20	1	11369.15	1 N	11671.80	−2	11916.25	−2
10910.97	−2	11508.00	3 N	11676.40	2 N	11916.85	−1 N
10917.14	1 N	11542.92	−1	11685.89	1	11918.02	0 N
10921.34	−1 N	11556.92	−1 N	11703.32	−1	11928.98	1 N
10950.86	1	11557.08	−1 N	11732.34	−1 N	11938.41	−2 N
10961.18	−2	11558.09	−1 N	11742.80	−2 NN	11943.90	0 n
11076.15	1	11559.00	−1 Nd	11744.78	−1 N	11951.72	0 n
11206.25	−1 N	11560.98	4	11746.09	0 N	11954.47	0
11230.17	−3 N	11562.90	−2 d	11797.55	0	11982.97	0 N
11239.9	−3 N	11563.69	0 N	11822.91	0 N		

*A solar line of −3 intensity is nearby.

Some intensity corrections are noted: λ 9753 Fe, + 1 (not −2); λ 10667 Cr, −1 (not +2); λ 11448, −1N (not 5N); λ 11645, −3 (not 0N). For 11633 Atm, read 11635. No corrections given beyond 11984 Å where the Mohler *Table* begins. Numerous classifications can now be added to this *Table* as well; the only serious correction found in the present spectral interval is at λ 12239.50, given as ⊙Fe, but found to be atmospheric.

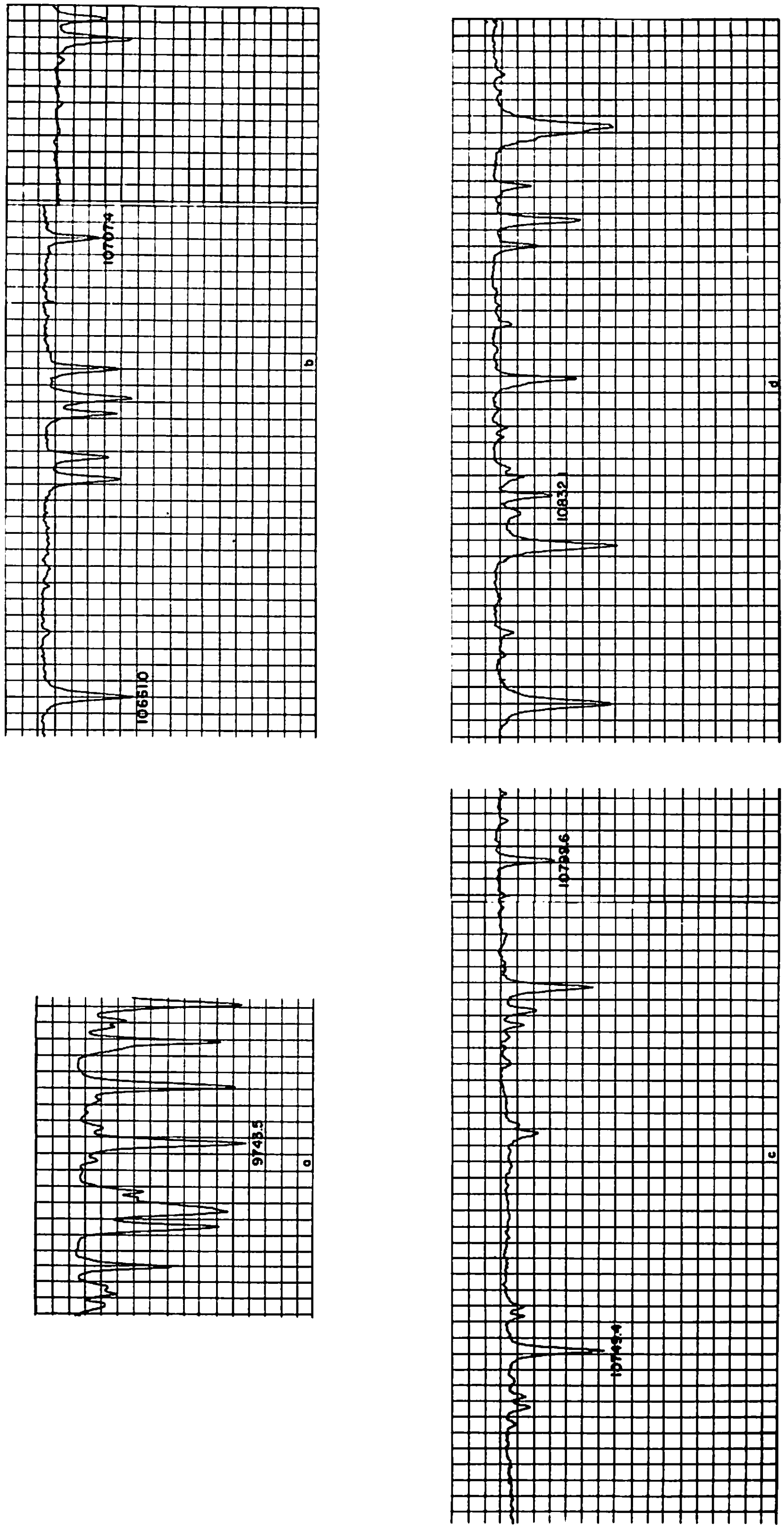

Fig. 1M Part of Michigan Atlas that matches Fig. 1 (1M–9M reproduced with permission).

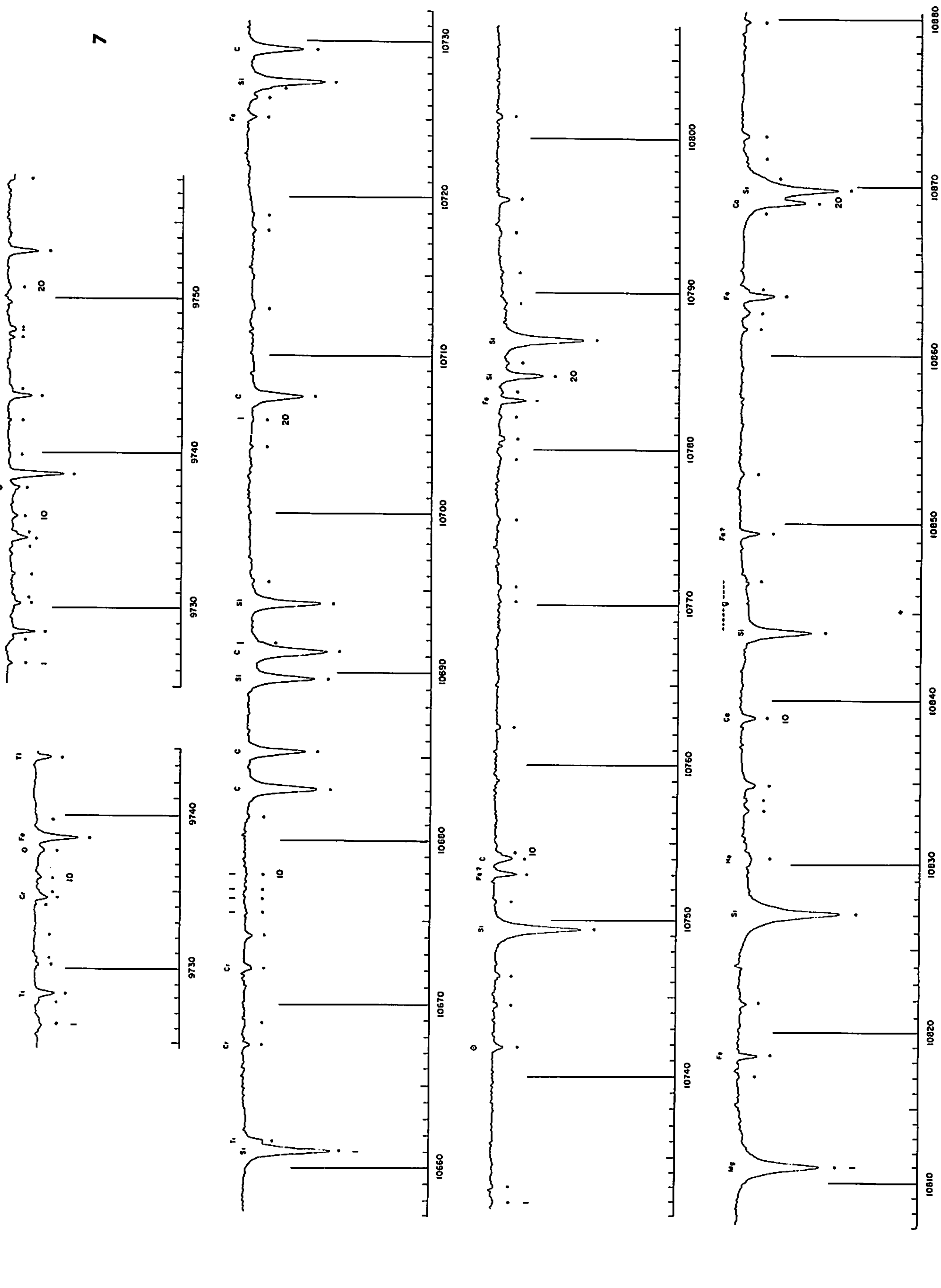

Fig. 1 Solar Spectrum λλ 9725–9758 and 10657–10880, in four strips (cf. Table 1).

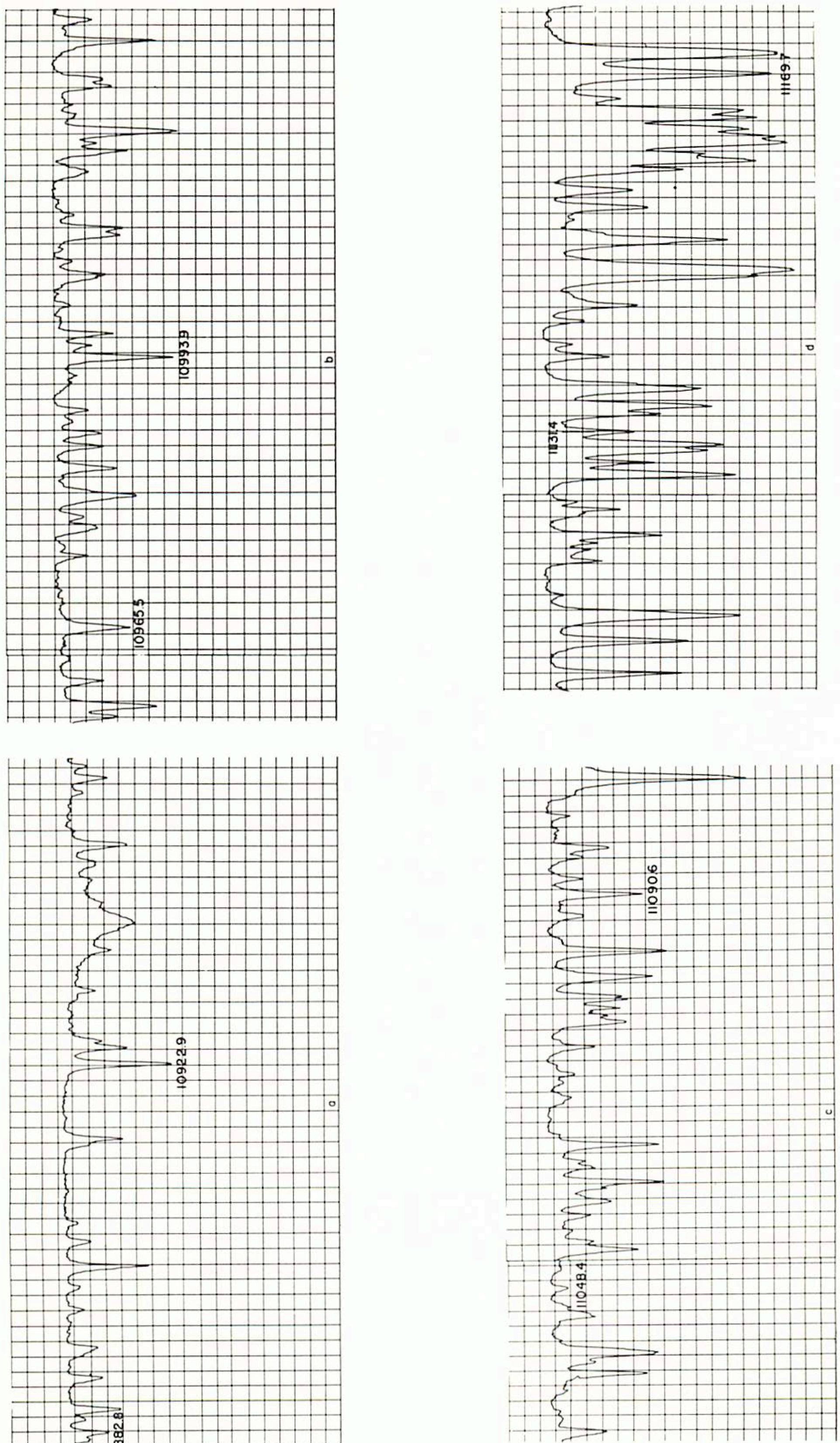

Fig. 2M Part of Michigan Atlas that matches Fig. 2.

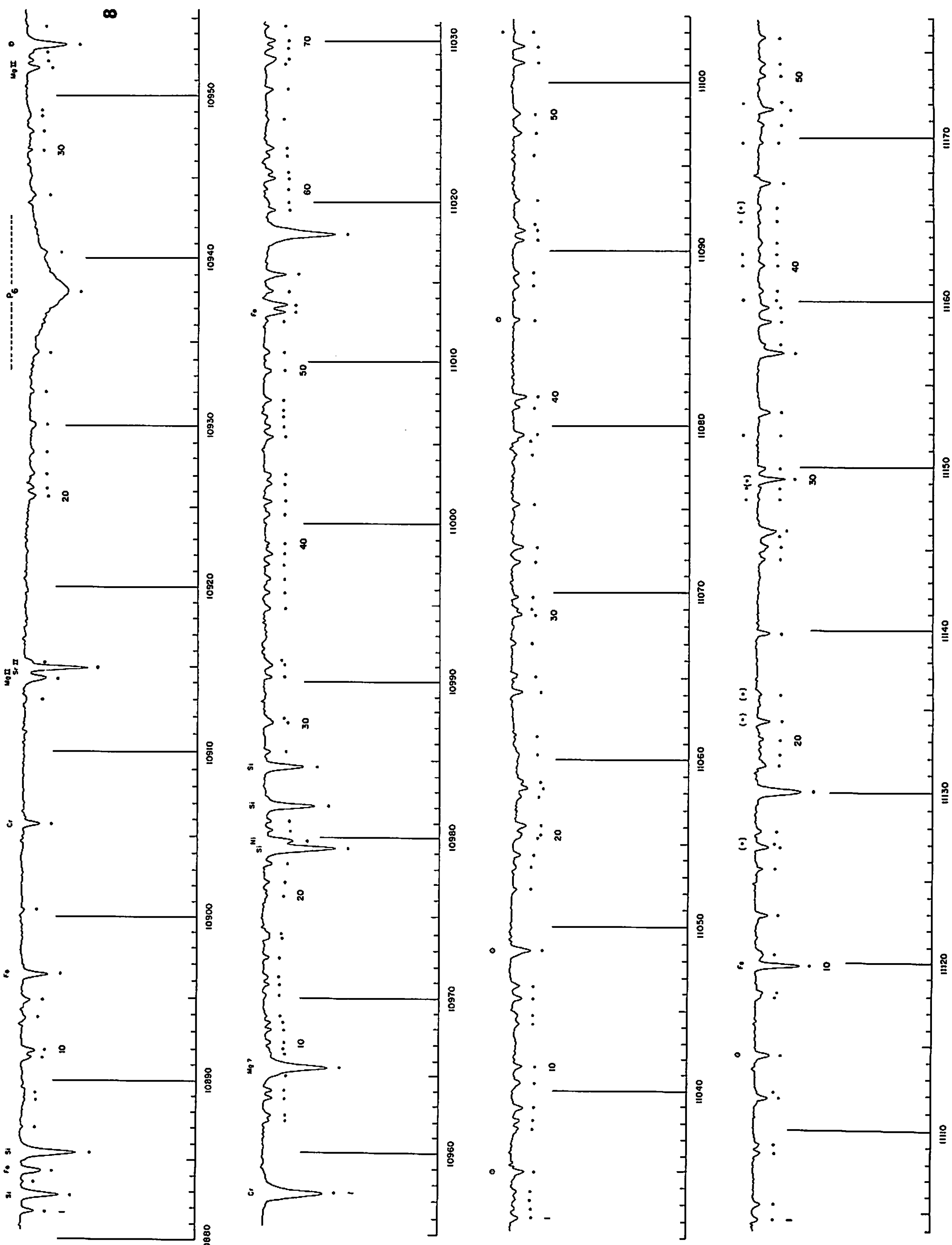

Fig. 2 Solar Spectrum λλ 10880–11177, in four strips (cf. Table 1).

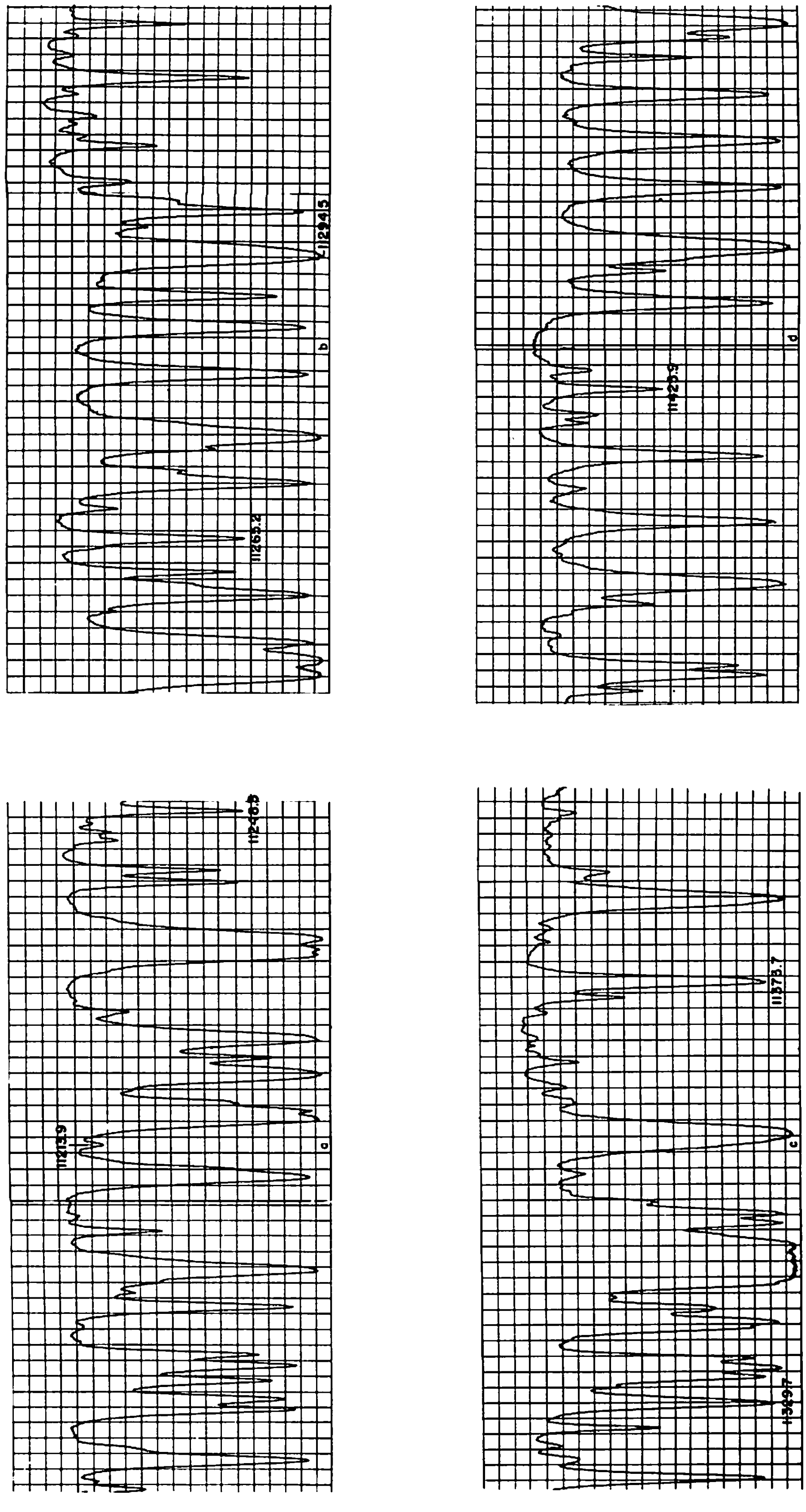

Fig. 3M Part of Michigan Atlas that matches Fig. 3.

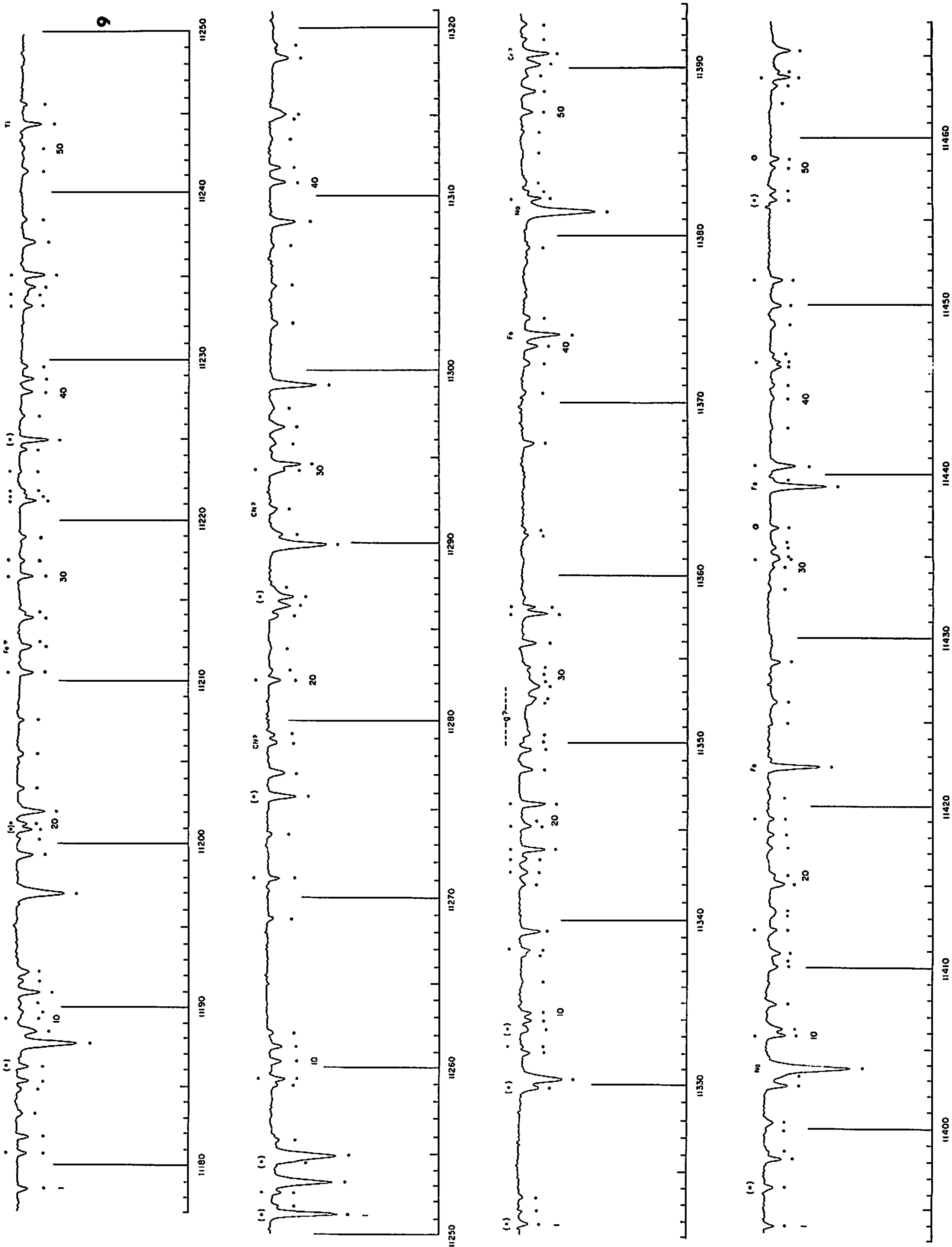

Fig. 3 Solar Spectrum λλ 11177–11467, in four strips (cf. Table 1).

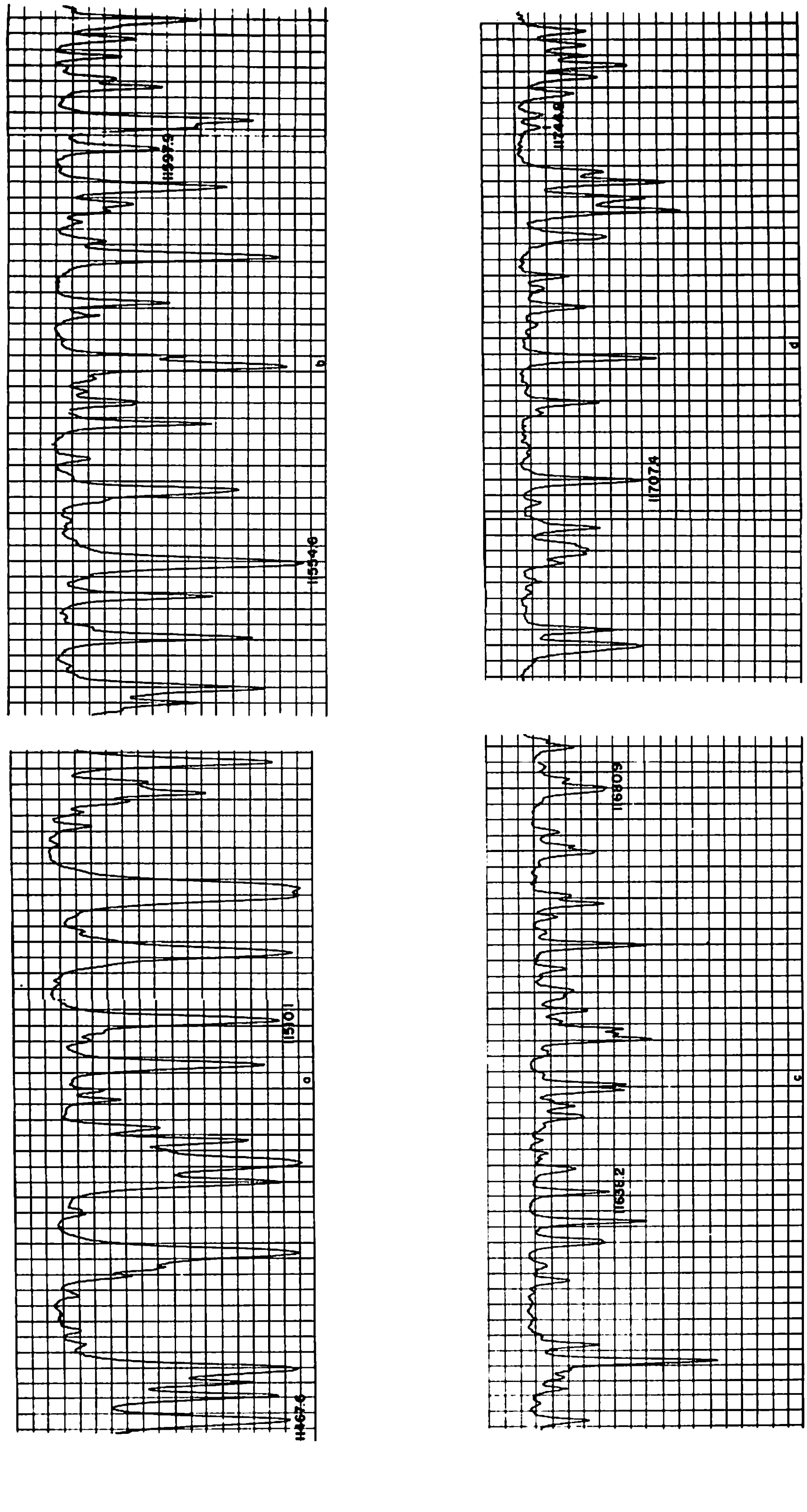

Fig. 4M Part of Michigan Atlas that matches Fig. 4.

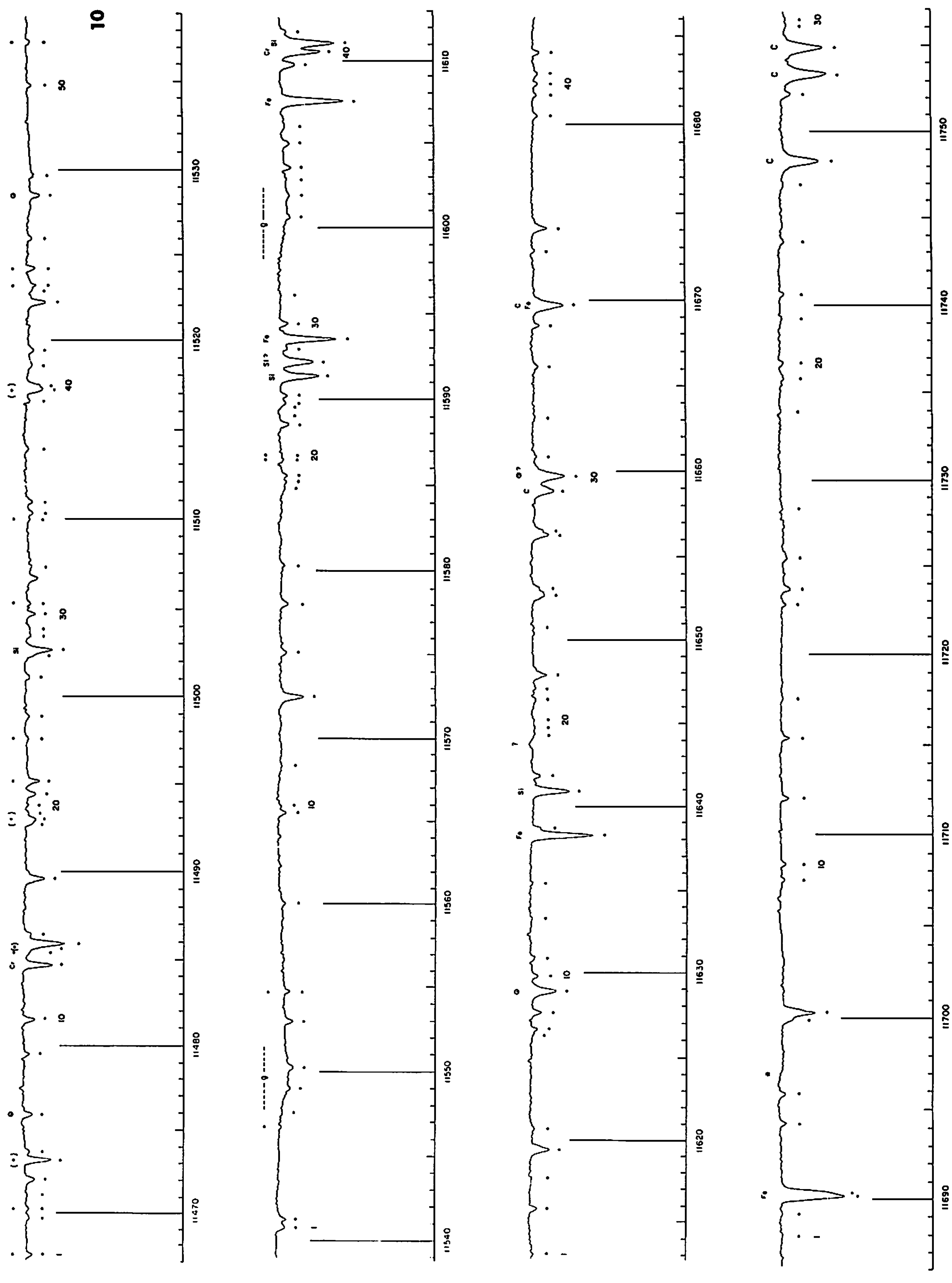

Fig. 4 Solar Spectrum λλ 11467–11757, in four strips (cf. Table 1). Asterisk indicates minor course change in aircraft (some vignetting).

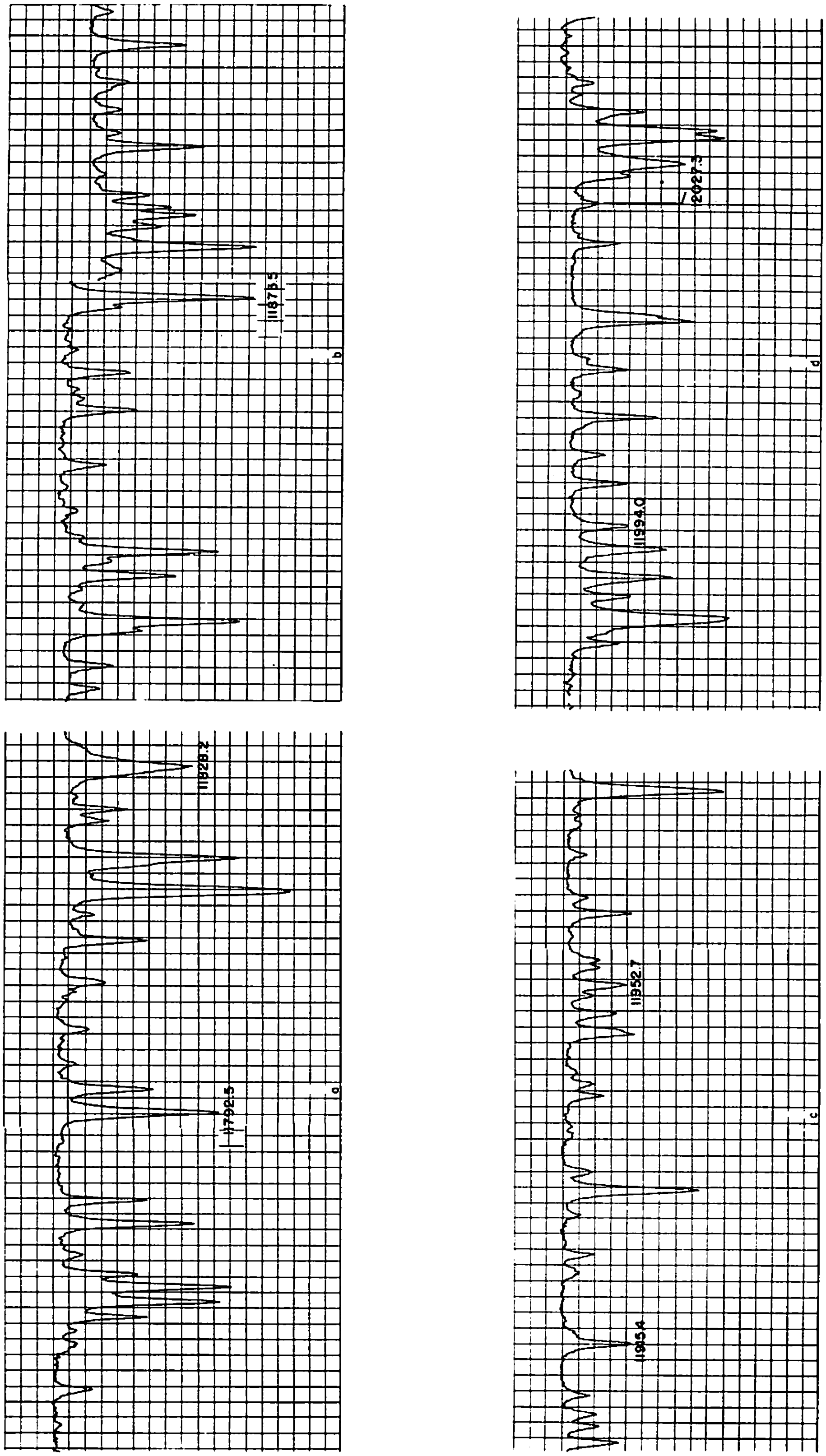

Fig. 5M Part of Michigan Atlas that matches Fig. 5.

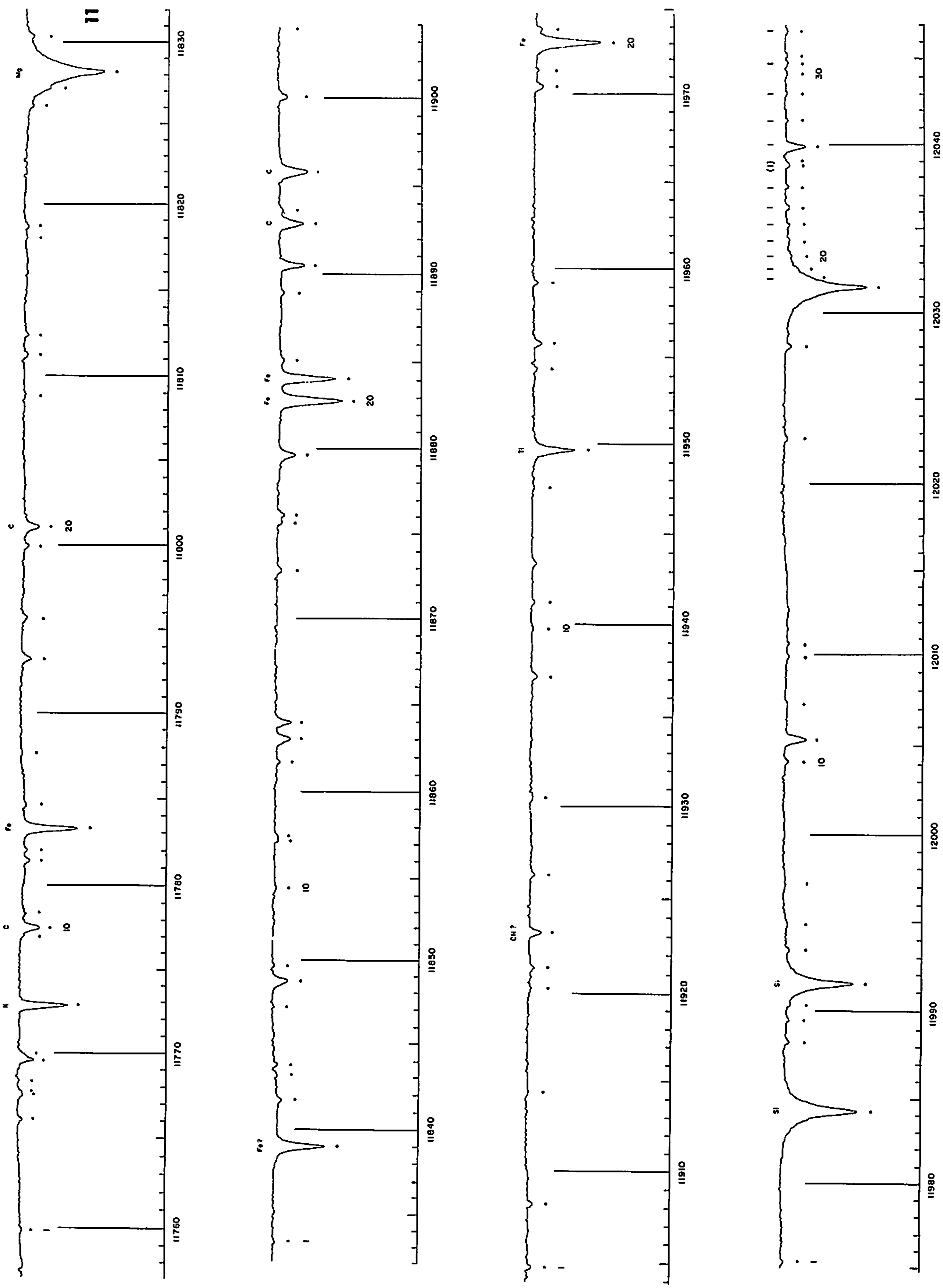

Fig. 5 Solar Spectrum λλ 11757–12047, in four strips (cf. Table 1).

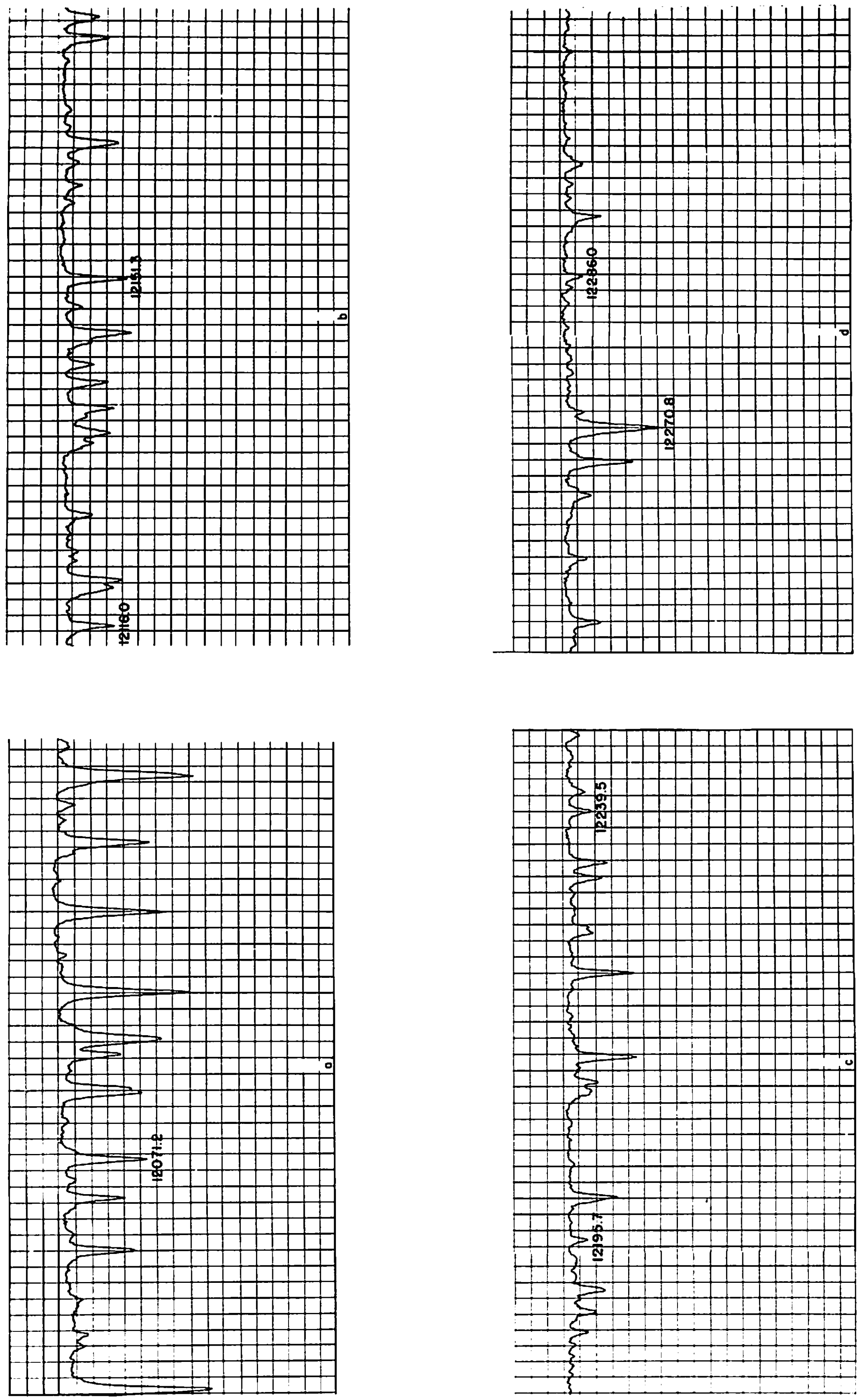

Fig. 6M Part of Michigan Atlas that matches Fig. 6.

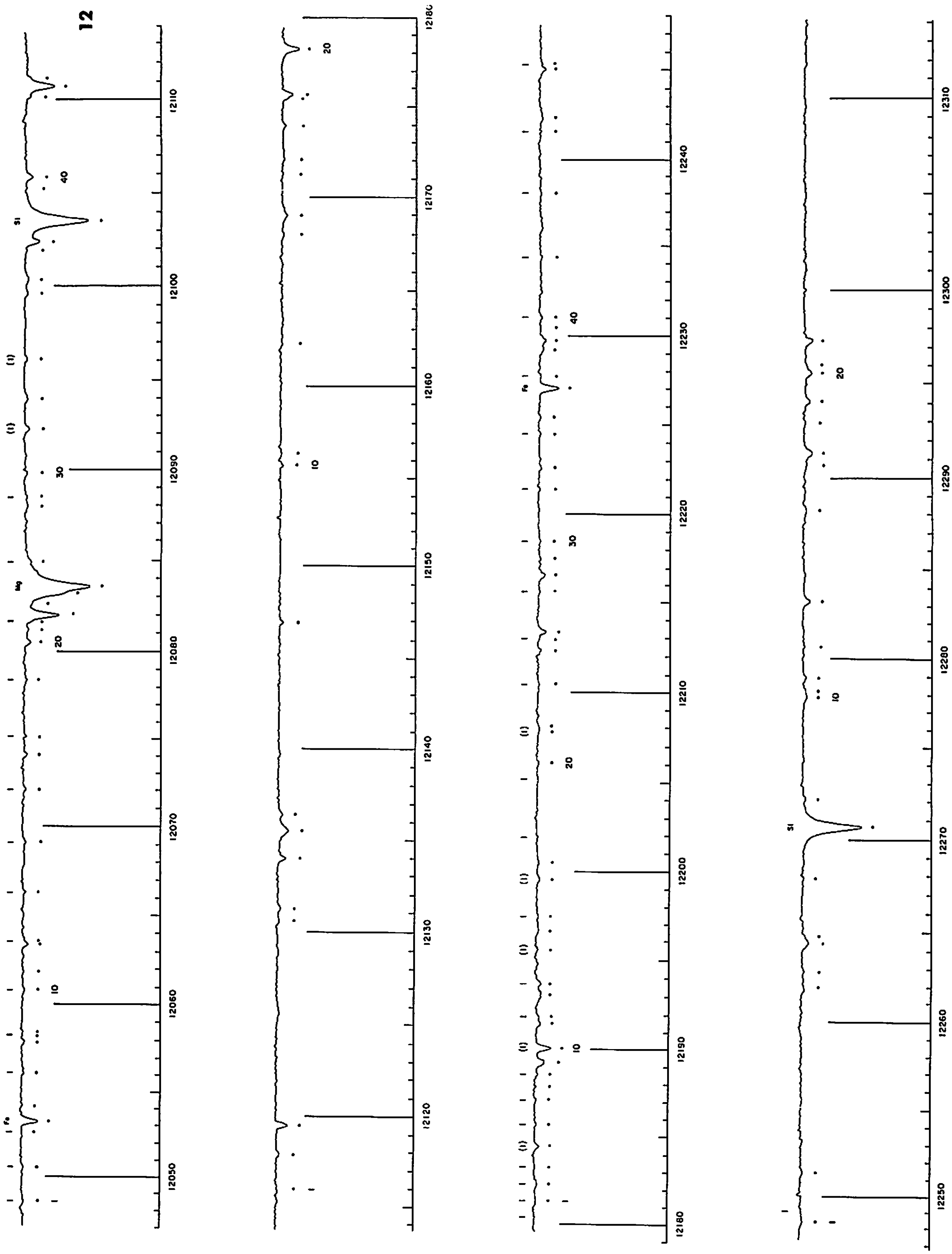

Fig. 6 Solar Spectrum λλ 12047–12314, in four strips (cf. Table 1).

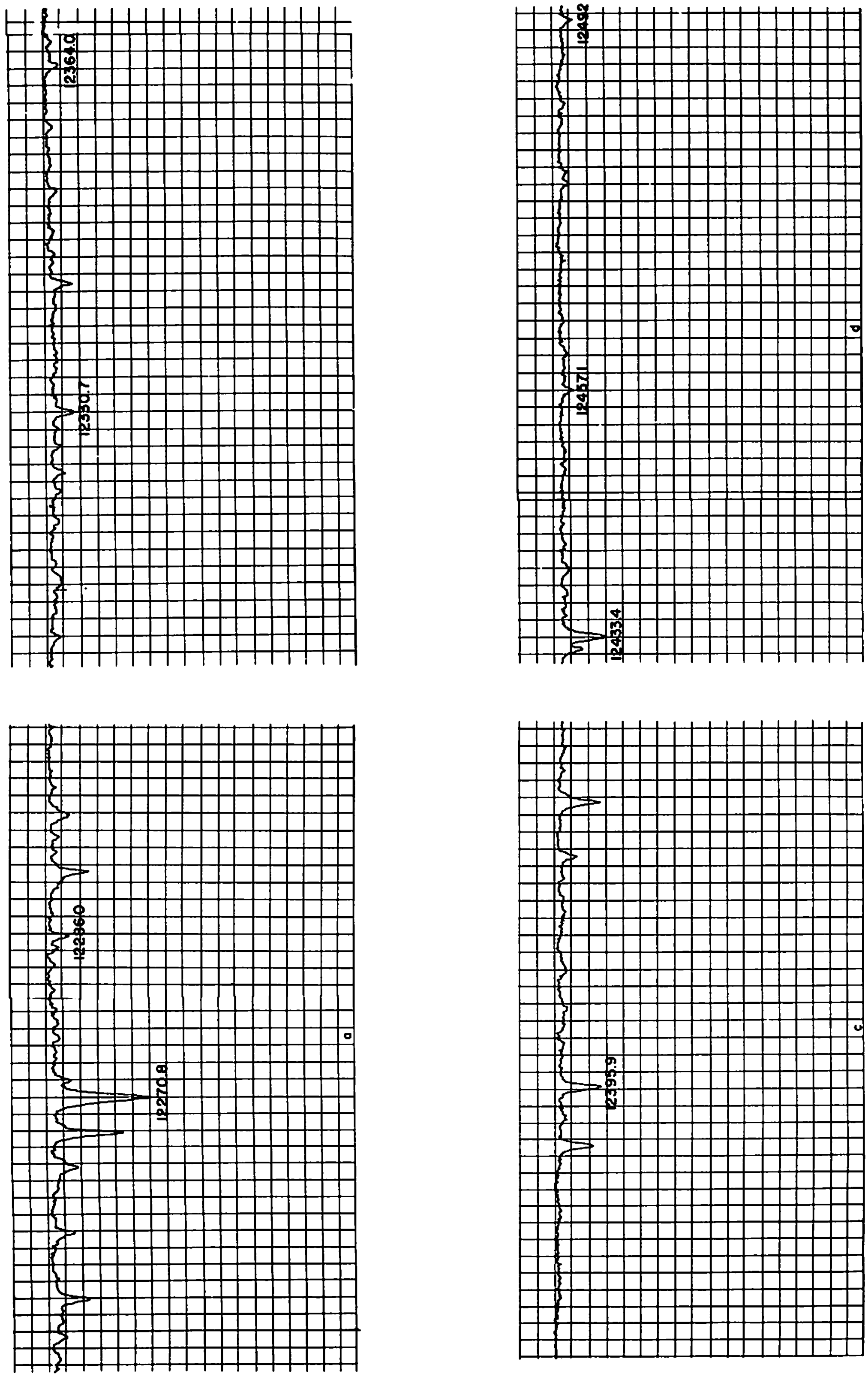

Fig. 7M Part of Michigan Atlas that matches Fig. 7.

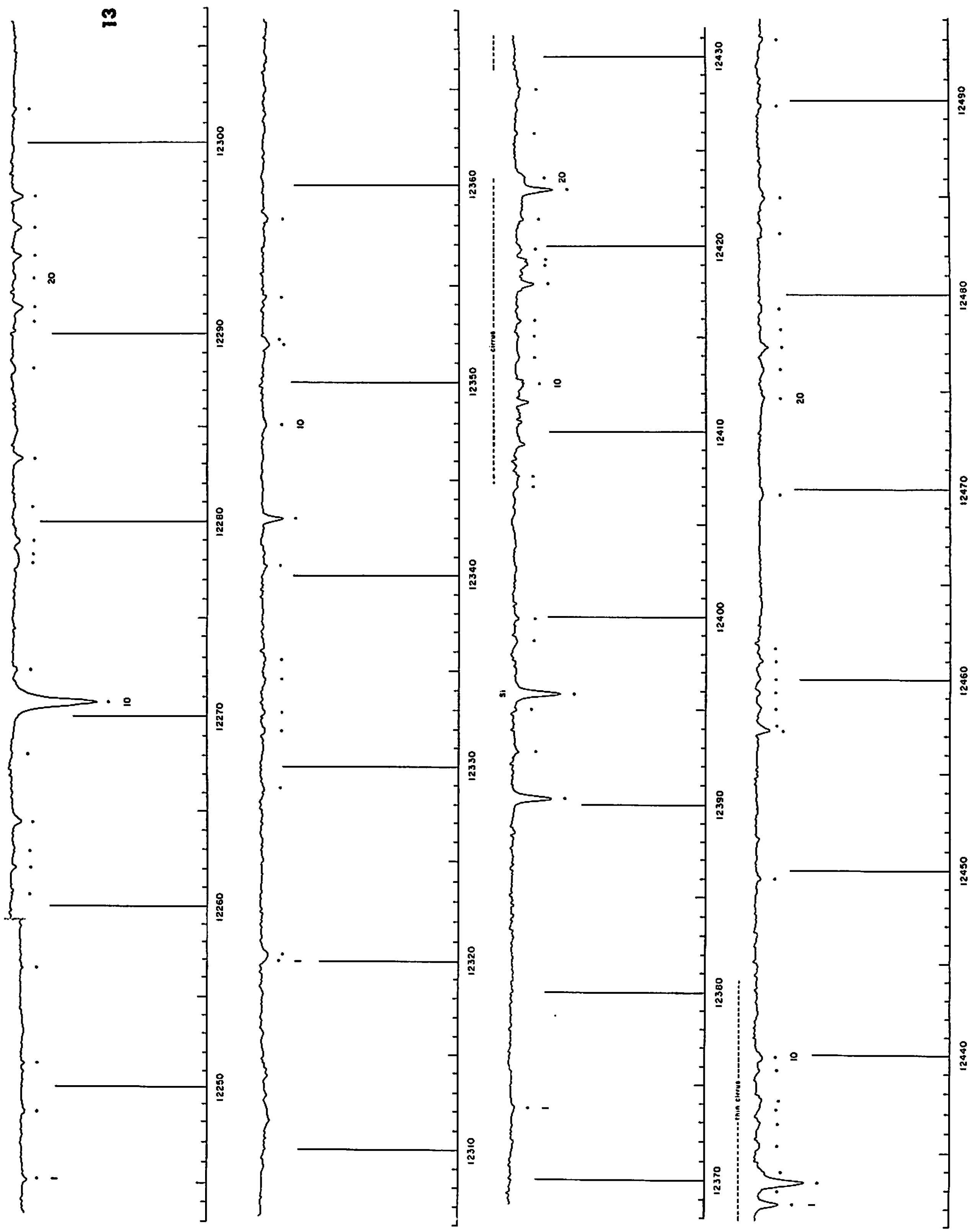

Fig. 7 Solar Spectrum λλ 12244–12494, in four strips (cf. Table 1).

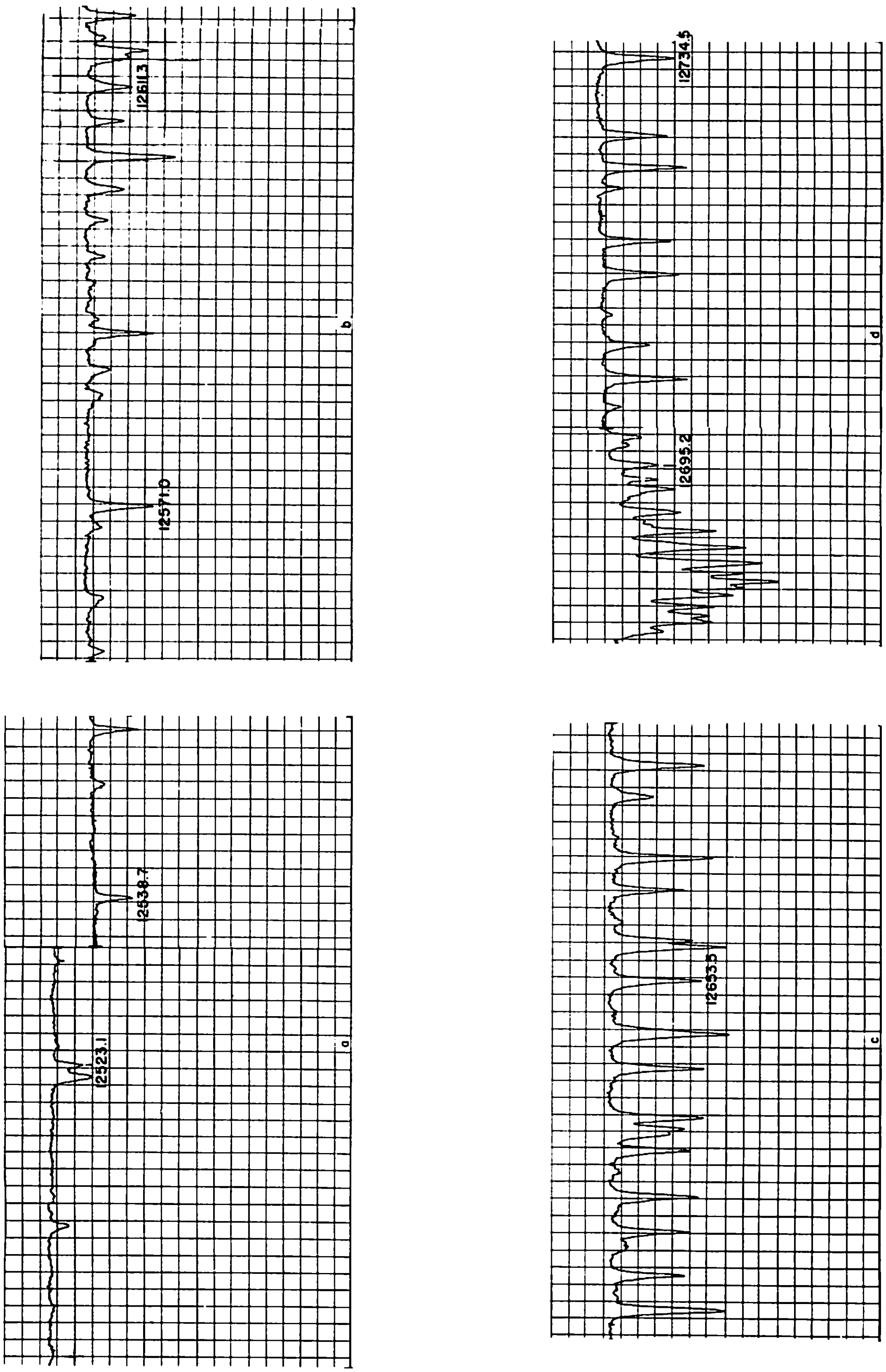

Fig. 8M Part of Michigan Atlas that matches Fig. 8.

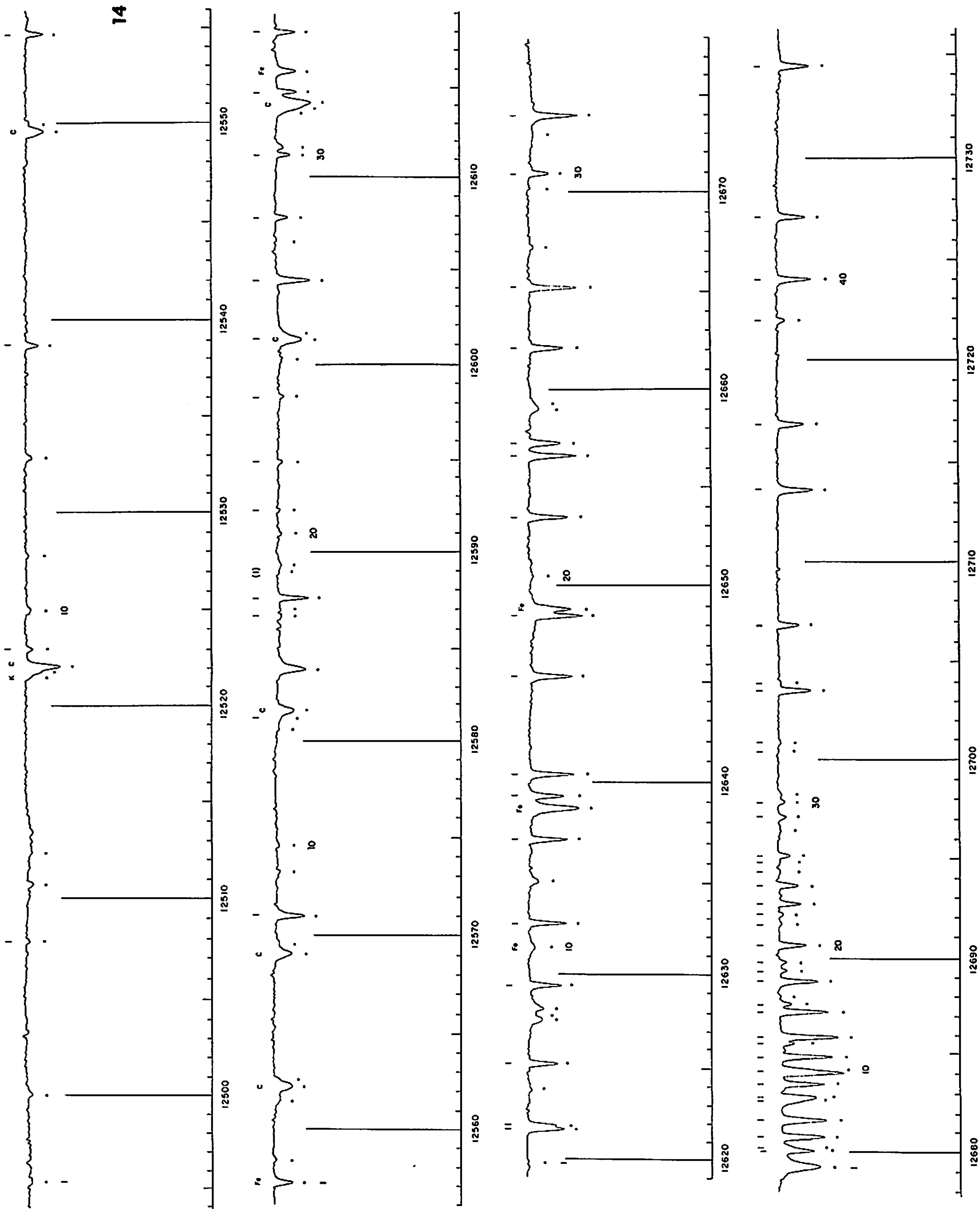

Fig. 8 Solar Spectrum λλ 12494–12736, in four strips (cf. Table 1).

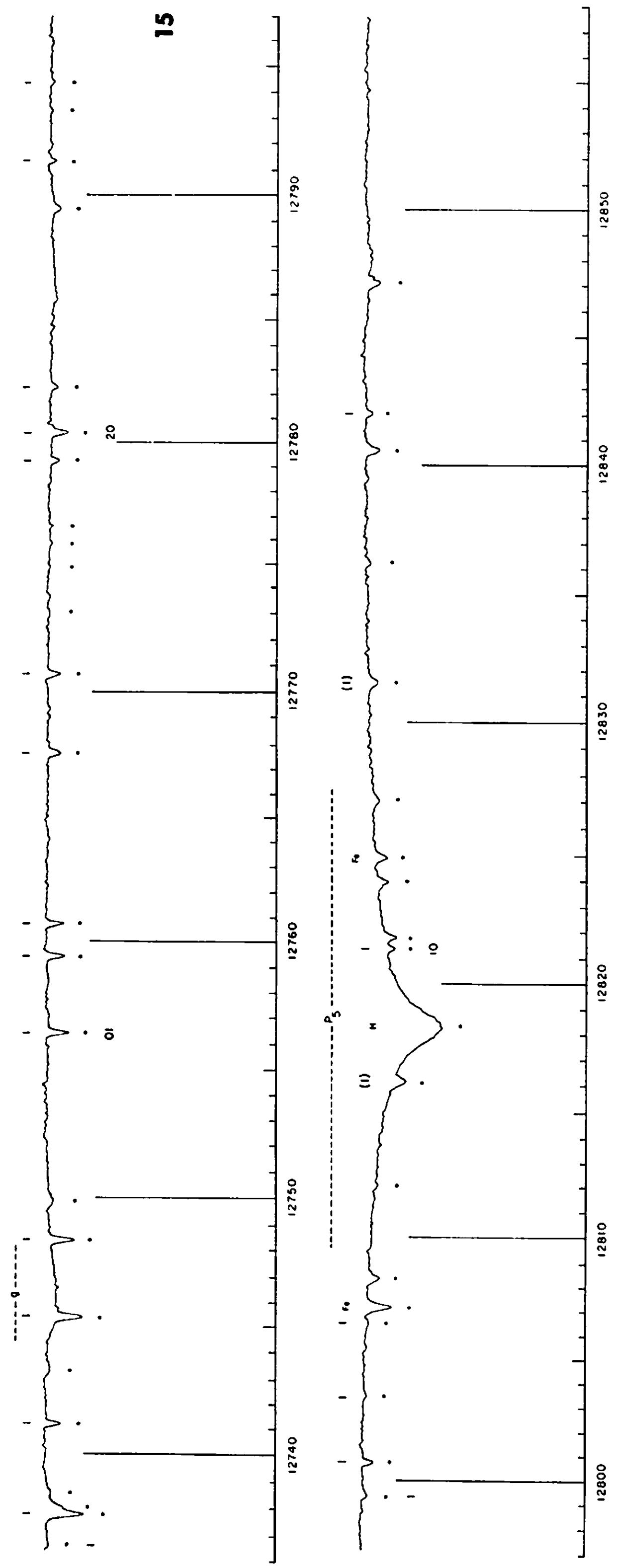

Fig. 9 Solar Spectrum λλ 12736–12857, in two strips (cf. Table 1).

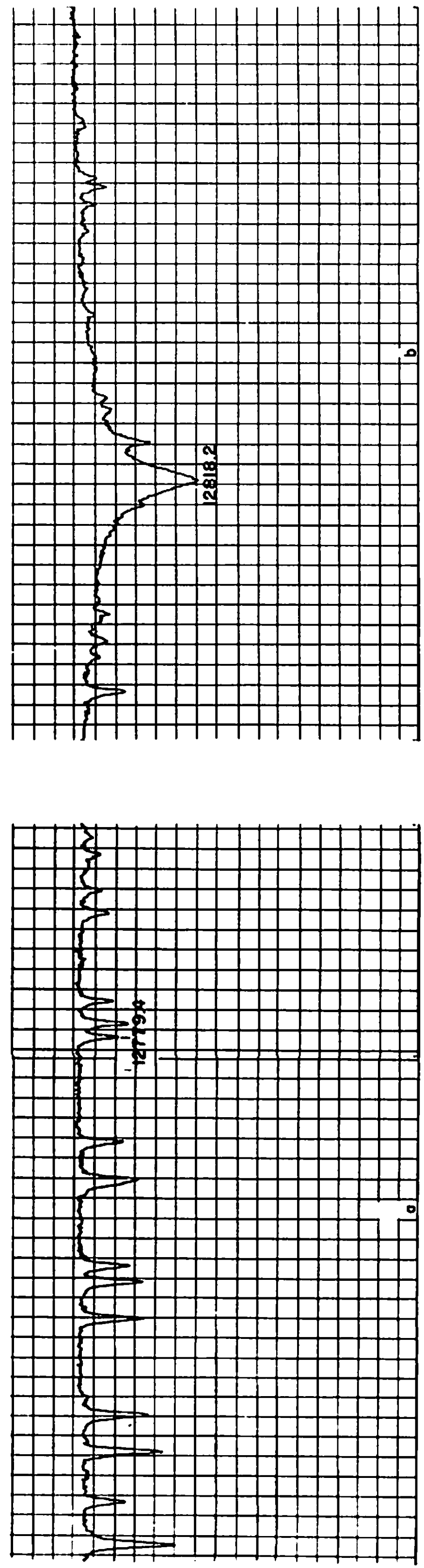

Fig. 9M Part of Michigan Atlas that matches Fig. 9.

NsG 161-61 and the University of Arizona Institutional Grant NGR-03-002-091.

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Addendum

Spectrum of the 1.13 μ H_2O Band

by UWE FINK, L. A. BIJL AND A. THOMSON

Figures 1–4 reproduce two sets of spectra of the 1.13 μ water-vapor band, covering the interval from λλ 11111–11613 Å. They were obtained with the 4-meter spectrometer as used in the solar spectrum observations, mounted in the LPL laboratory. The upper spectrum refers to a laboratory air path at ambient pressure (705 mm), totaling 18.5 meters, 17 meters of which was within the spectrometer. The lower spectrum was obtained with the spectrometer flushed with dry nitrogen gas, and refers essentially to the outside air path of about 1.5 meters. The water-vapor contents are estimated from a wet-and-dry bulb hygrometer and correspond to about 7 microns precip. water per one meter air path. The upper spectrum therefore represents approximately 130 microns of precip. water, the lower spectrum 10 microns, both at p = 705 mm.

The slit width and the detector width were both 0.10 mm, the time constant of the amplifier 0.12 sec. and the filter RG-8, all as in the solar observations. Also, the scan and recorder speeds were the same as in the solar records.

The wavelength scale was derived by one of us (L. A. B.) and corresponds accurately to the scale shown in the solar records, both being based on that of the Liège *Atlas*. Owing to slight irregularities in the grating drive, the dispersions in the two water-vapor spectra are not quite identical.

The width of the water-vapor lines in the laboratory records is somewhat larger than that of the telluric lines in the solar spectra, presumably due to the higher pressure in the laboratory (930 mb vs < 200 mb).

Mrs. A. Agnieray assisted in the preparation of the figures.

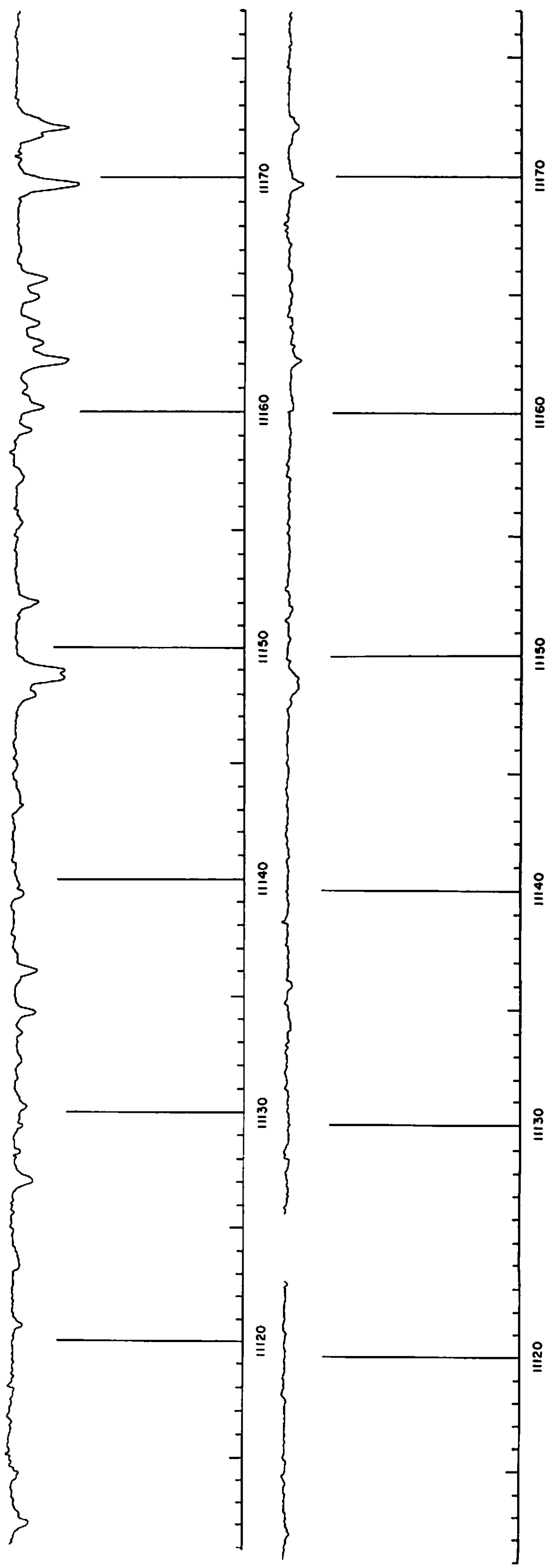

Fig. 1A Laboratory spectrum of water vapor, λλ 11111–11177 Å.

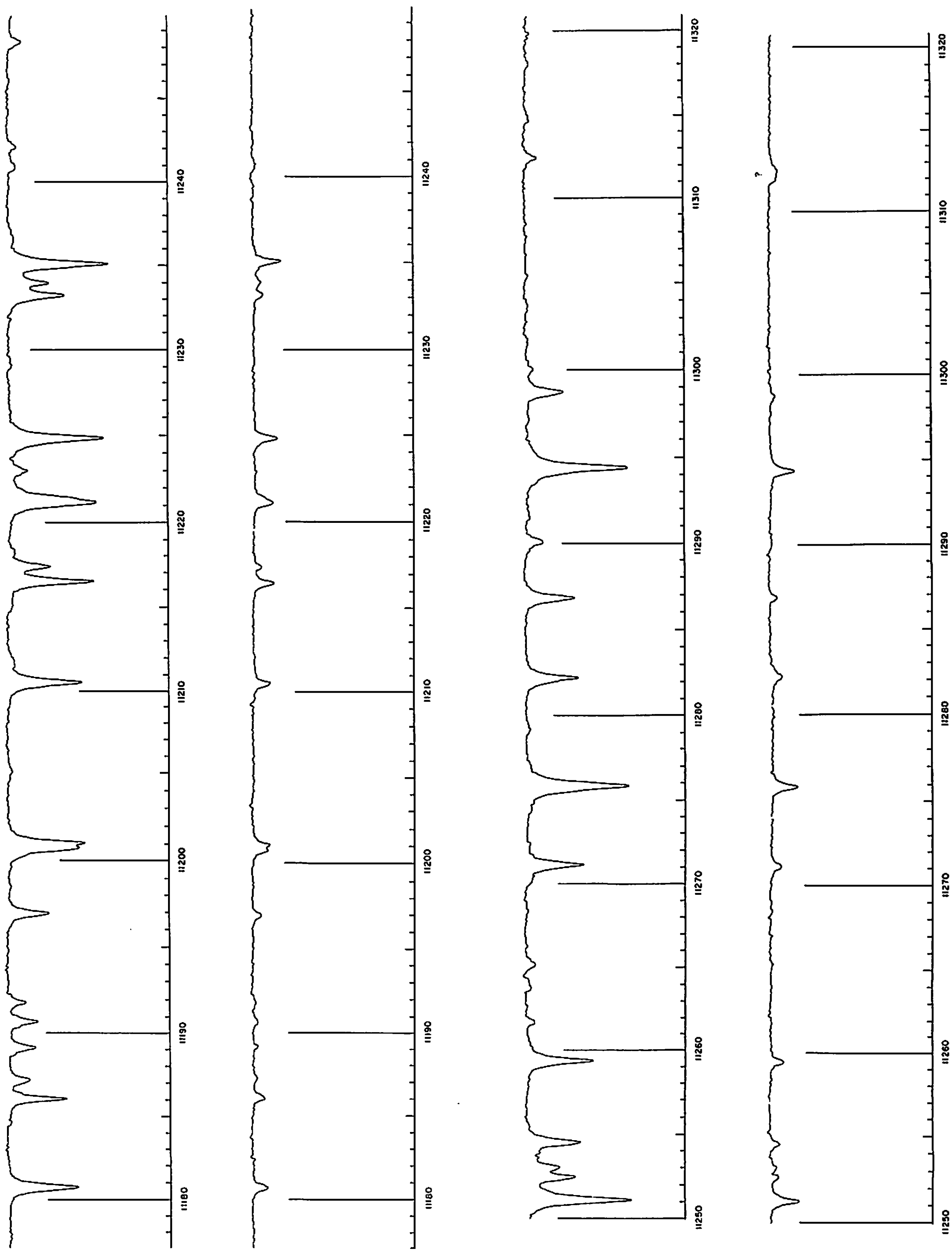

Fig. 2A Laboratory spectrum of water vapor, λλ 11177–11321 Å.

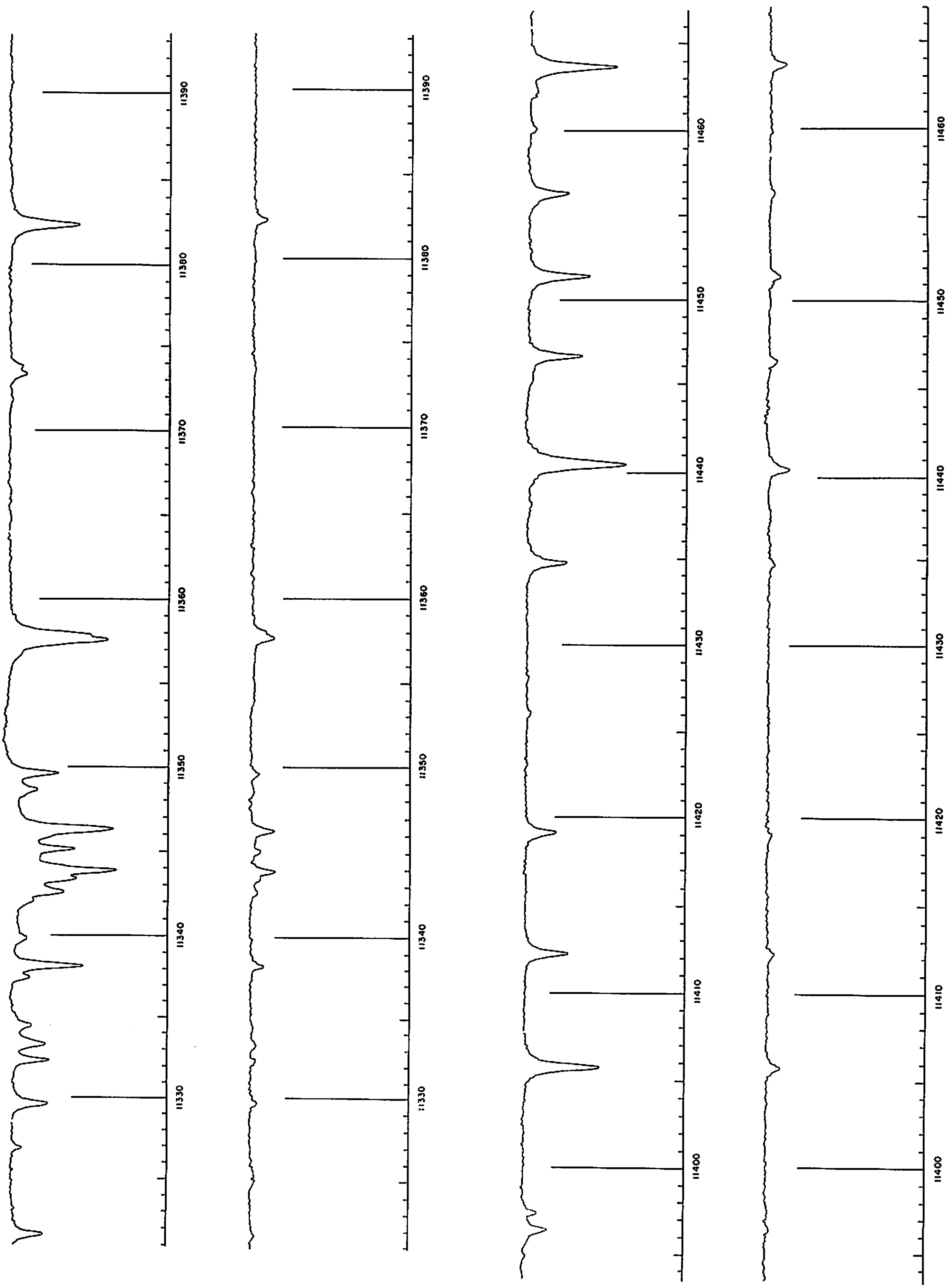

Fig. 3A Laboratory spectrum of water vapor, λλ 11321–11467 Å.

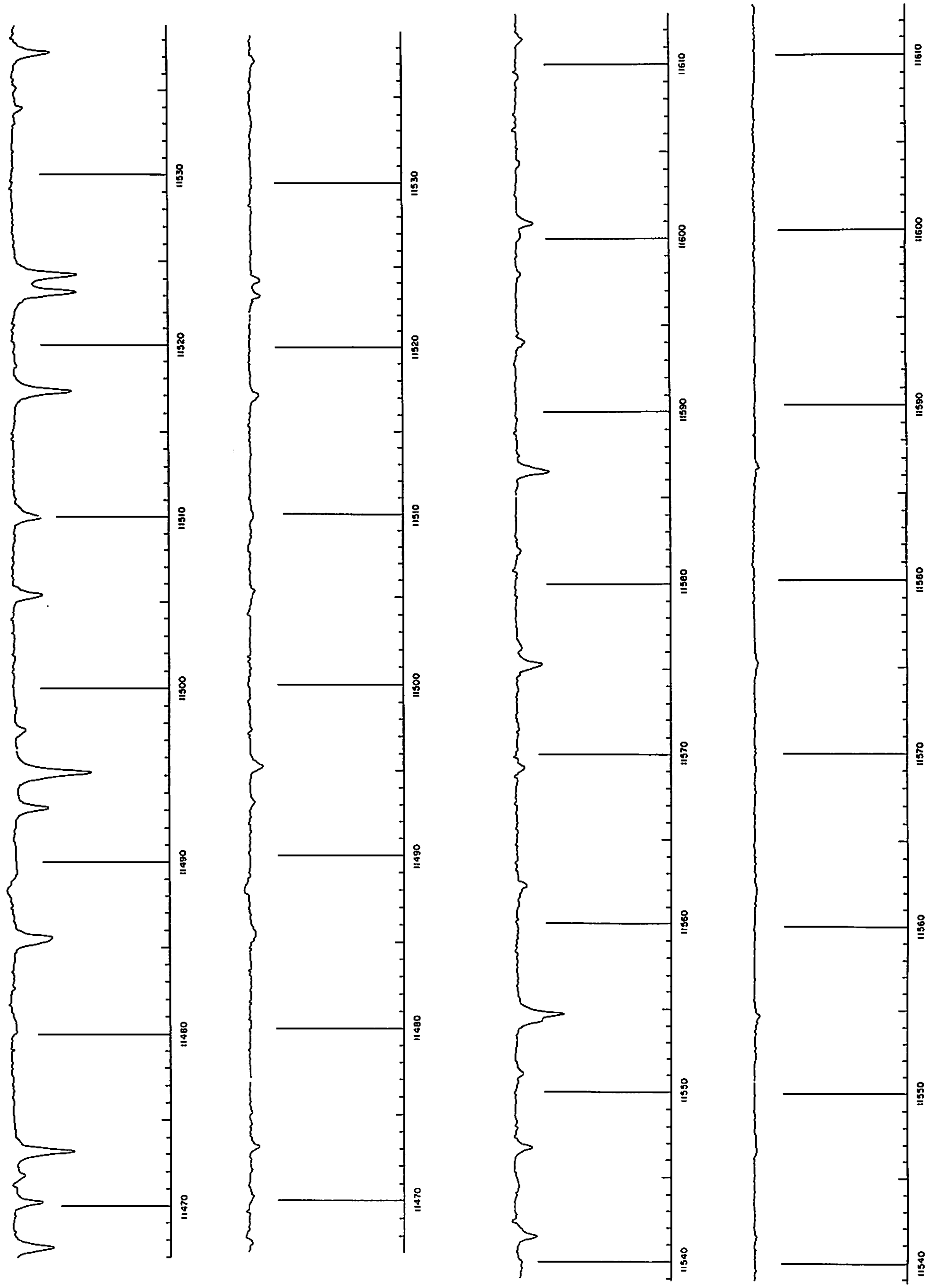

Fig. 4A Laboratory spectrum of water vapor, λλ 11467–11613 Å.