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FOREST SERVICE
U. S. DEPARTMENT OF AGRICULTURE
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FIRE WEATHER AND FIRE BEHAVIOR AT THE 1968 CANYON FIRE

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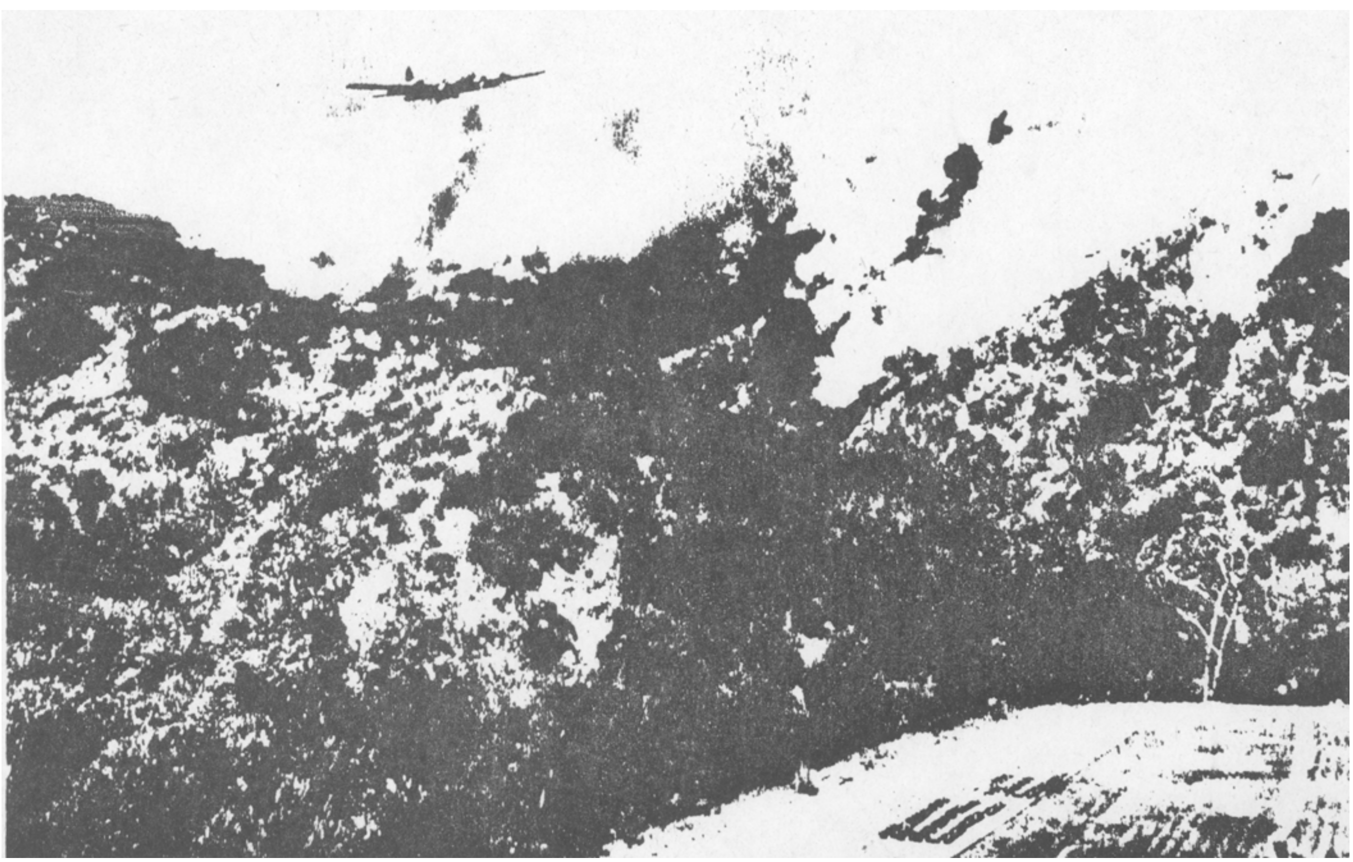

U.S.D.A. FOREST SERVICE RESEARCH PAPER PSW-55 1969

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Acknowledgments

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This paper also benefited from the technical reviews by Dr. James G. Edinger, University of California, Los Angeles, Mark J. Schroeder, ESSA Weather Bureau; and George R. Fahnestock and William G. Morris, Forest Service, U.S. Department of Agriculture.

Fighting a wildland fire has often been likened to fighting a military battle. In battles there are casualties, in spite of efforts to protect the fighters; so there were in the Canyon Fire of August 24, 1968, when seven Los Angeles County firefighters and their foreman were overrun by a fire flareup and fatally burned. The Canyon Fire burned 20,200 acres before it was finally brought under control; this was indeed a major battle in a continuing war against destructive wildfires.

In the intensive investigation that followed the accident, the weather conditions, fuel conditions, and topography in the Glendora Ridge sector, where the accident occurred, were carefully analyzed.

This paper summarizes the information gathered and the conclusions reached as to the influence of these three factors on the behavior of the fire. Obviously, the particular conditions that prevailed here may never be found in another fire. Nevertheless, the specific information about one fire may help to give fire control personnel a better understanding of fire behavior in general, and so help to prevent future accidents.

The Canyon Fire started on August 23, 1968, near Canyon Inn under Santa Ana wind conditions. The Glendora Ridge sector of the fire quickly spread southerly on an expanding front toward the front country above Sierra Madre Avenue in Azusa, California. It also spread easterly along the upper slopes of the south side of Glendora Ridge. The fire then hacked down the slopes above Sierra Madre Avenue. It reached the developed area along Sierra Madre Avenue first just east of the San Gabriel Canyon. Although occasionally hard pressed, the firemen were able to stop the fire as it reached the toe of the main slope. However, the fire continued to spread eastward and downslope on Glendora Ridge and eastward along the front country above Sierra Madre Avenue.

By morning of August 24, the eastward spread of the fire on the upper slopes of Glendora Ridge had been stopped along the firebreak above Azusa Pacific College. The fire also has not crossed the lower half of the firebreak on the spur ridge above Los Angeles County Fire Station 97. The open fireline thus extended east and west between these two firebreaks *(fig. 1)*.[1] In this area, the fire was backing down the slope toward Sierra Madre Avenue. The relatively slow spread down a steep and broken south slope was characterized by frequent hot fire runs diagonally up the slope as the fire worked its way into favorable positions of fuel and topography. These runs or flareups were most prevalent in the numerous steep ravines and became more frequent and violent as the day progressed and the atmosphere became very unstable. The crew from Camp 4-4 was caught in one of these flareups while working along the wall of a steep ravine.

In the investigations that followed the fire, information was gathered on the weather conditions that preceded and accompanied the fire; on the fuel types present and their characteristics, as determined by sampling of similar unburned material adjacent to the fire area as well as examination of the area itself; and on the topographical features of the accident site. Fire behavior was determined through evidence on the scene and through the accounts of witnesses.

Fire behavior in any instance is the result of the integrated effects of weather, fuel, and topography. In the Canyon Fire, topography and fuel conditions dominated behavior, but the sudden flareup that caused the disaster may have been caused by the atmospheric instability and the surge of the sea breeze into the area.

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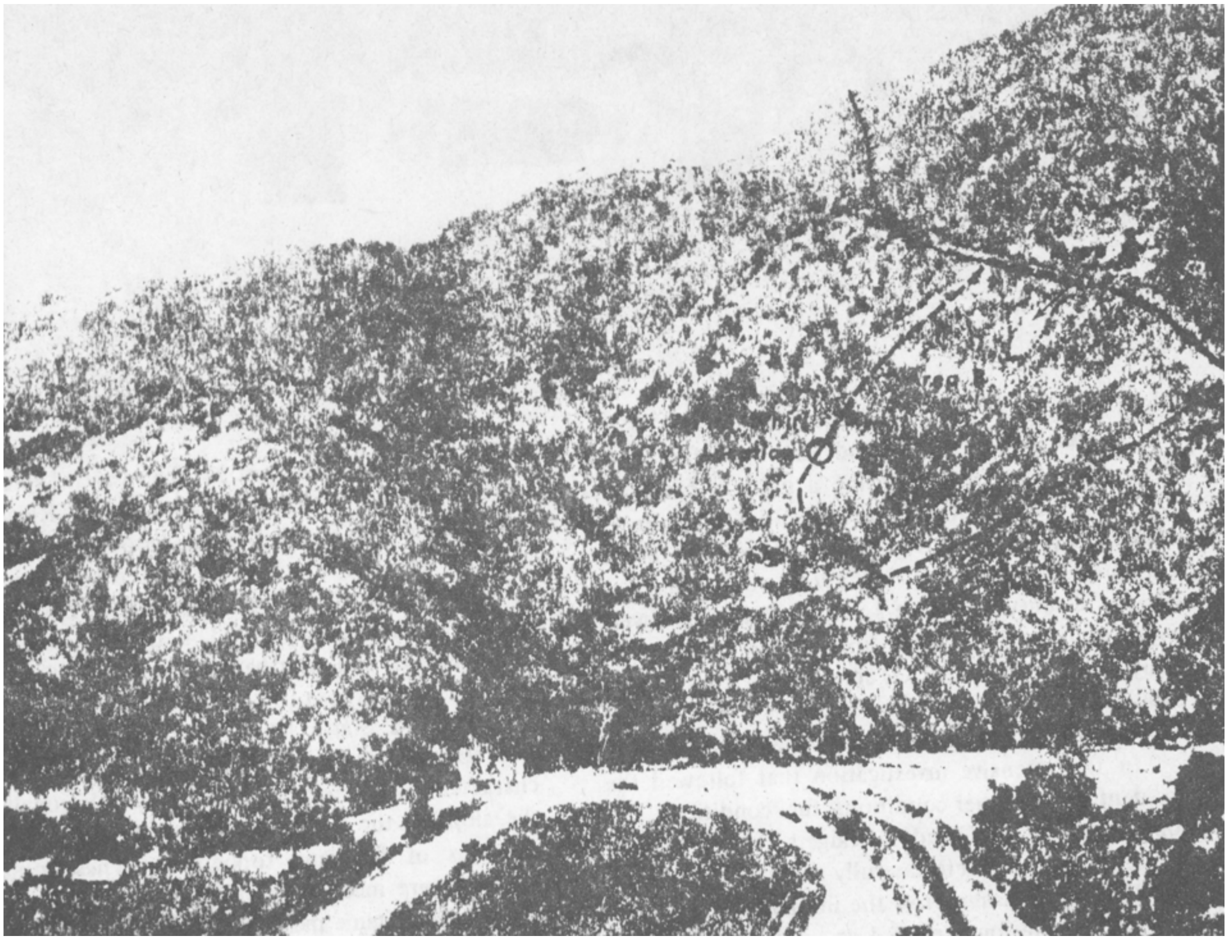
[1] Following photographs courtesy of Mike Castro, *Pomona Progress. Bulletin* cover, figs. 23 to 26.



(Photo by Los Angeles County Fire Department)

Figure 1.–*Approximate fire front location at 0831 hours on August 24, 1968. See Fig. 22 for topographic map of fire area.*

GENERAL WEATHER SITUATION

The synoptic weather pattern, as well as the local conditions, before and during the fire, were analyzed. Fire danger records were also examined.

Before August 24, 1968

For several days prior to Thursday, August 22, 1968, the synoptic weather situation had changed very little. An upper-level trough along the coast of California had kept temperatures down and humidities up *(fig. 2)*. On August 21 low pressure covered the desert areas of southern California and higher pressures existed along the coast *(fig. 3)*. This resulted in moderate to strong onshore flow over all the Los Angeles Basin, with the marine air layer extending up to about 1,500 feel. The surface temperatures were below normal as they had been for some time.

By August 22, surface winds had changed generally to a more westerly direction that still allowed onshore flow. The height of the marine layer was about the same as on August 21. Temperatures remained relatively low although they were generally slightly higher than on August 21 *(table 1)* the dewpoint changed little also. The situation altered rapidly, however, after the 22nd. The low center aloft that was over the Rocky Mountains in the morning on the 23rd *(fig. 4)* had moved to eastern North Dakota by the morning of the 24th *(fig. 5)*.

A big change in surface conditions occurred on August 23 also *(fig. 6)*. The gradient was reversed from the orientation it had on August 21. High pressure had become centered to the northeast of Los Angeles, and there was a Santa Ana condition with a

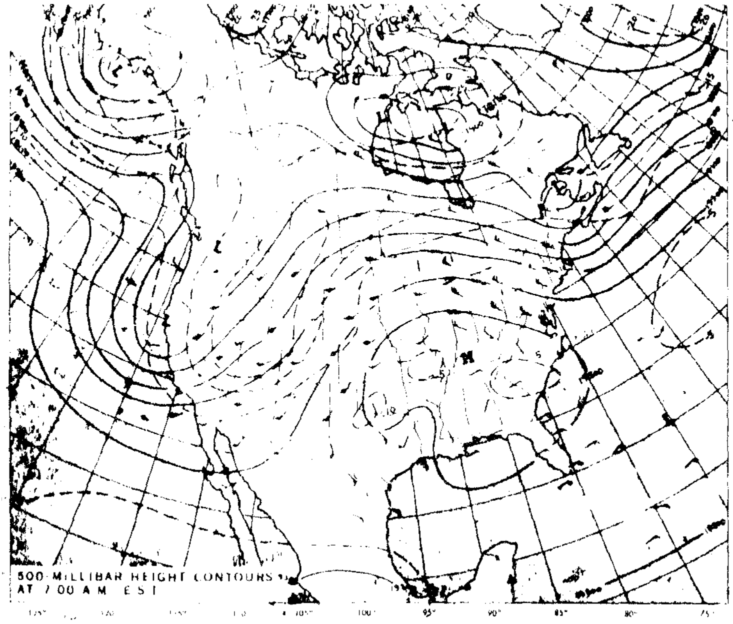


Figure 2. – *500 millibar height contours at 0500 local, August 21, 1968.*

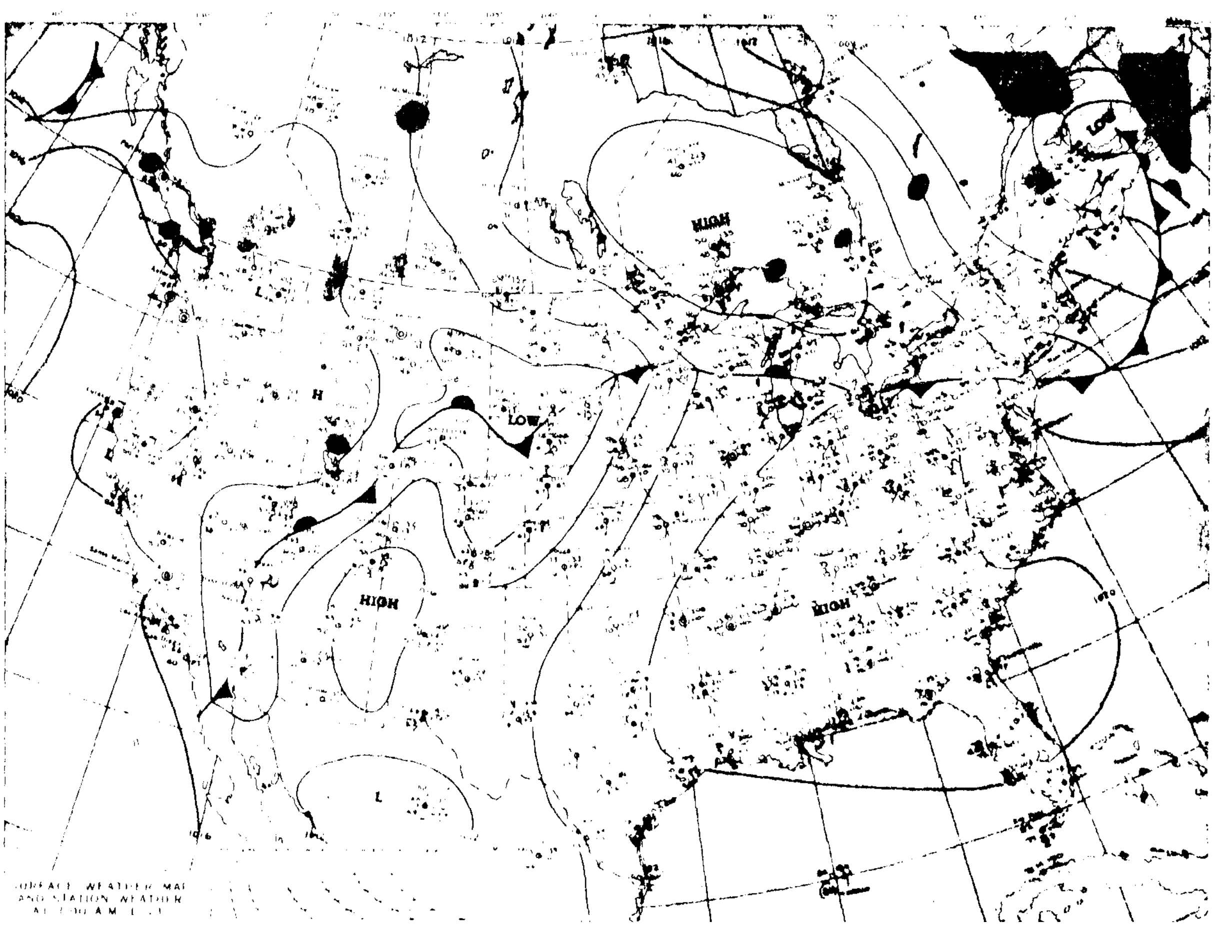


Figure 3.–*Daily surface weather map for 0500 local August 21, 1968.*

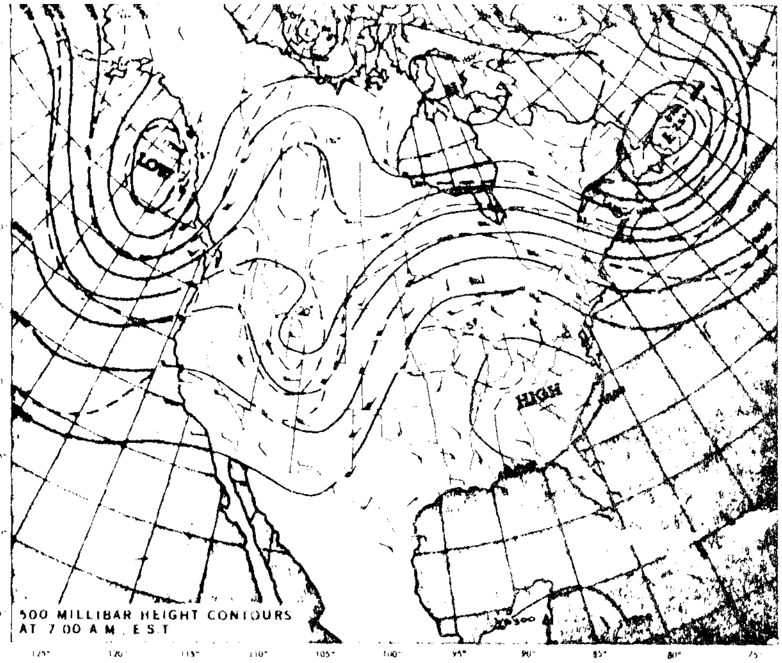
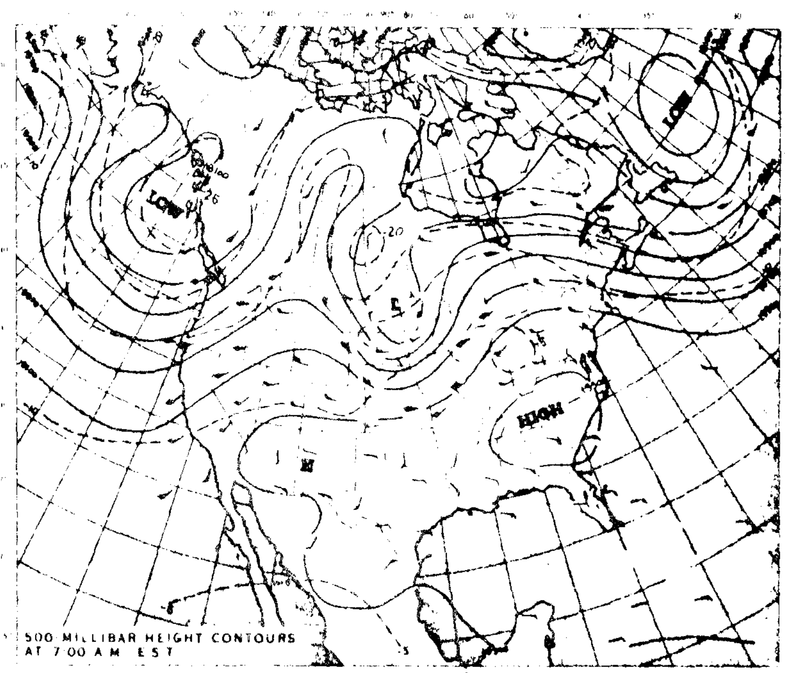


Figure 4. – *500 millibar height contours at 0500 local, August 23, 1968.*

Figure 5. – *500 millibar height contours at 0500 local, August 24, 1968.*



7.8 mb. pressure difference between Los Angeles and Tonopah *(table 1).* This compared to a 1.4 mb. difference at the same time the day before. The upper-air flow had become anticyclonic on the 23rd. The ridge was over the coast of southern California and temperatures at 500 mb. were high *(fig. 4).* Temperatures on the surface in southern California also jumped on the 23rd; for example, the temperature at Los Angeles was 90º F. at 1100[2] as compared to 70°F. the day before. Dewpoint temperatures also dropped significantly *(table 1).* Surface winds were more northerly. Accompanying this increase in temperature, decrease in humidity, and slight change in wind direction was also a large decrease in atmospheric static stability, and the marine layer was eliminated from the coastal area *(fig. 7).*

[2] All times in this report are Pacific daylight saving time (P.d.s.t.), unless shown otherwise.

Table 1.–*Temperature, wind observations. and sea-level pressure differences, 1100 P.d.s.t., August 21 to 24, 1968*

Date (1968)	Dry bulb temperature	Dewpoint	Wind direction	Windspeed	Pressure difference
	° F.	*° F.*		*M.p.h.*	*Mb.*[1]
			LOS ANGELES		
8/21	69	55	WSW	12	+3.3
8/22	70	57	WSW	12	-1.4
8/23	90	35	N	6	-7.8
8/24	76	65	SW	5	-3.7
			BURBANK		
8/21	74	42	E	6	–
8/22	75	57	S	6	–
8/23	90	35	NNW	6	–
8/24	85	37	SE	7	–
			ONTARIO		
8/21	74	52	WSW	6	–
8/22	76	50	SSW	10	–
8/23	88	44	SE	6	–
8/24	87	42	S	7	–

[1] Pressure at Los Angeles, California minus pressure at Tonopah, Nevada.

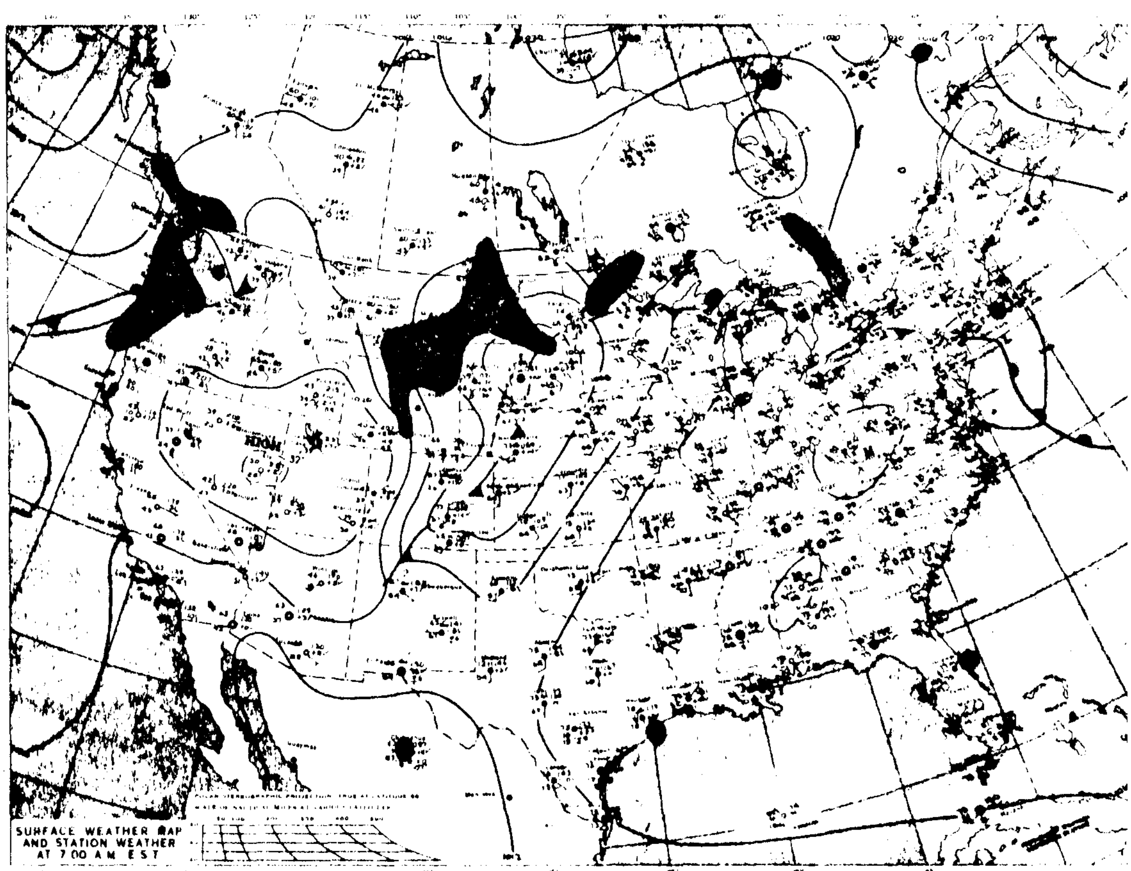


Figure 6. –*Daily surface weather map for 0500 local, August 23, 1968.*

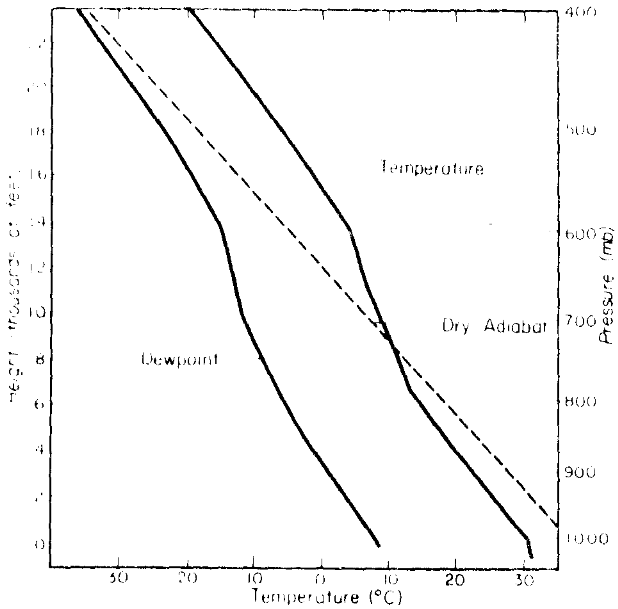


Figure 7.–*Radiosonde observation at Los* Angeles, *1300 local, August 23, 1968.*

On August 24, 1968

On August 24, the day of the accident, there were only high clouds and visibility remained over 5 miles in the San Gabriel Valley and foothill region *(table 2).*

The isobaric pattern formed a surface cold area over southern California, so that winds over the area varied considerably in direction and speed *(fig. 8).* A layer of marine air was evident along the coast, but the low humidities and high temperatures at the fire area indicated the cool, moist marine air did not reach there. Temperatures had begun to fall again, especially near the coast, but were still high away from the coast (*table 1).*

No sounding at the fire location at the time of the accident is available; but a representative sounding for the fire area was constructed *(fig. 9)* from the sounding made at Los Angeles International Airport at 1300, the surface temperatures at Azusa, and the dewpoint temperatures in the area. The surface

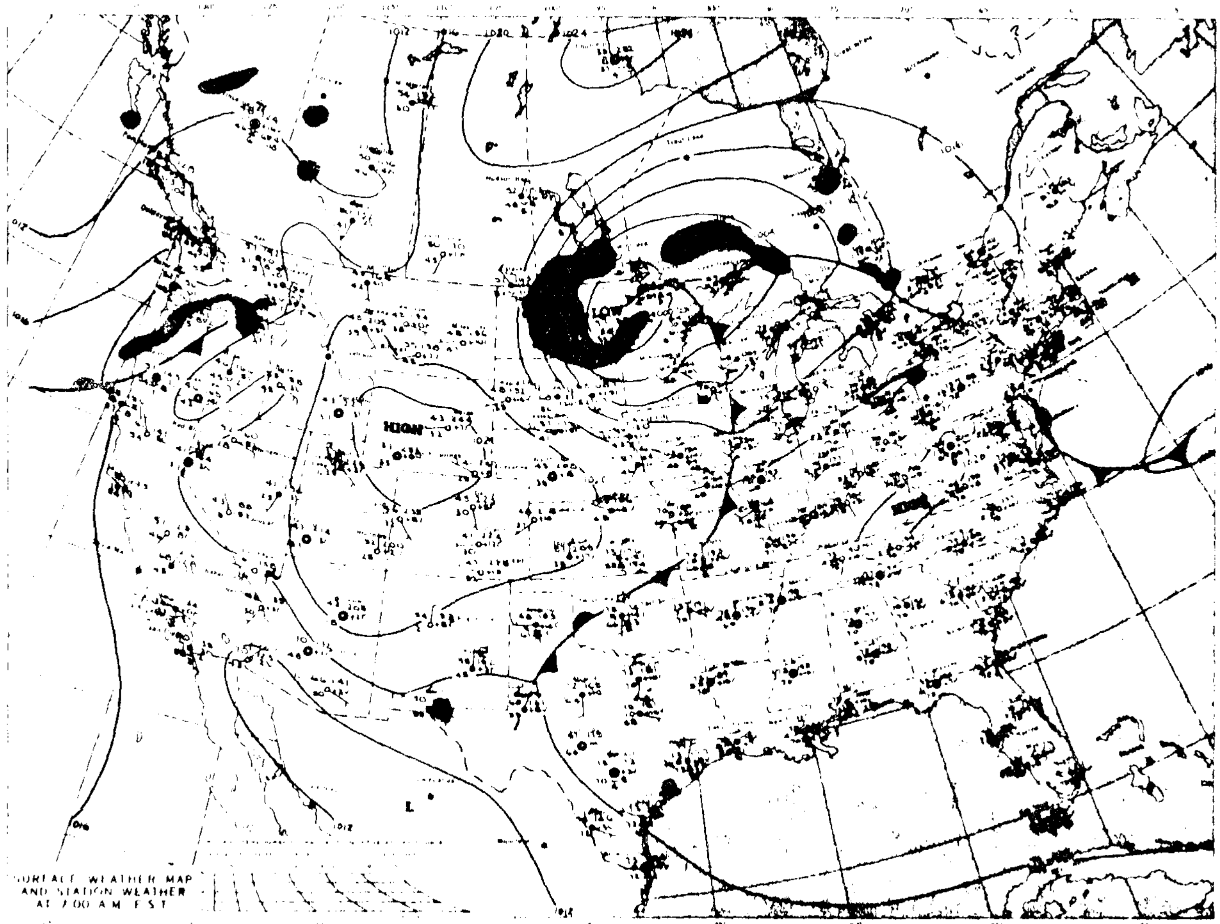


Figure 8. –*Daily surface weather map for 0500 local, August 24, 1968.*

Table 2.–*Weather observations for Angeles Basin and area, August 24, 1968*

Time (P.d.s.t.)	Sky condition	Visibility	Temperature	Dew-point	Wind direction	Wind speed	Relative humidity
		Miles	*ºF*	*ºF*		*M.p.h.*	*Pct.*
	LOS ANGELES						
0700	High broken	1	66	62	E	4	87
0800	Obscuration	0	63	63	SSE	5	100
0900	Obscuration	1/16	64	64	ESE	5	100
1000	Partial obscuration	1	72	65	– –	(1)	80
1100	Partial obscuration	2	76	65	SW	5	68
1200	Partial obscuration	3	77	64	SW	9	65
1300	high scattered	4	75	63	SW	12	66
1400	Clear	4	77	64	WSW	9	64
	LONG BEACH						
0700	Obscuration	1/8	65	64	SE	6	98
0800	Obscuration	1/2	65	64	SSE	5	98
0900	Scattered/high scattered	2-1/2	68	63	SSW	4	85
1000	High thin scattered	3	74	63	ESE	4	70
1100	High thin scattered	5	79	61	SSW	6	53
1200	High scattered	8	83	53	SSW	8	35
1300	high scattered	8	86	49	SSW	6	28
1400	High scattered	10	87	50	S	10	28
	ONTARIO						
0700	High scattered	15	64	41	N	1	43
0800	High overcast	6	70	43	SE	1	37
0900	High broken	6	77	43	NNW	1	30
1000	High broken	6	82	42	SW	2	25
1100	High scattered	8	87	42	S	7	21
1200	High scattered	8	90	44	WSW	5	20
1300	High scattered	15	91	47	SE	6	22
1400	High scattered	15	94	47	SSW	8	20

1 Calm.

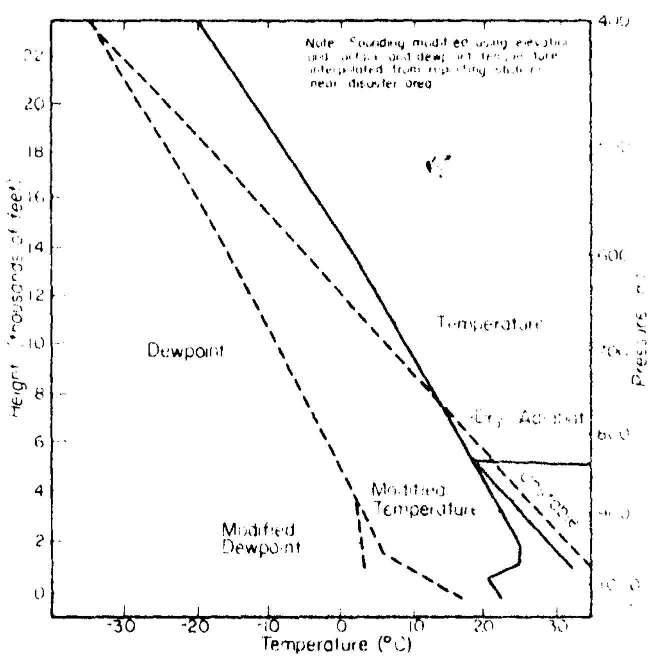


Figure 9. –*Radiosonde observation at Los Angeles, 1300 local, August 24, 1968.*

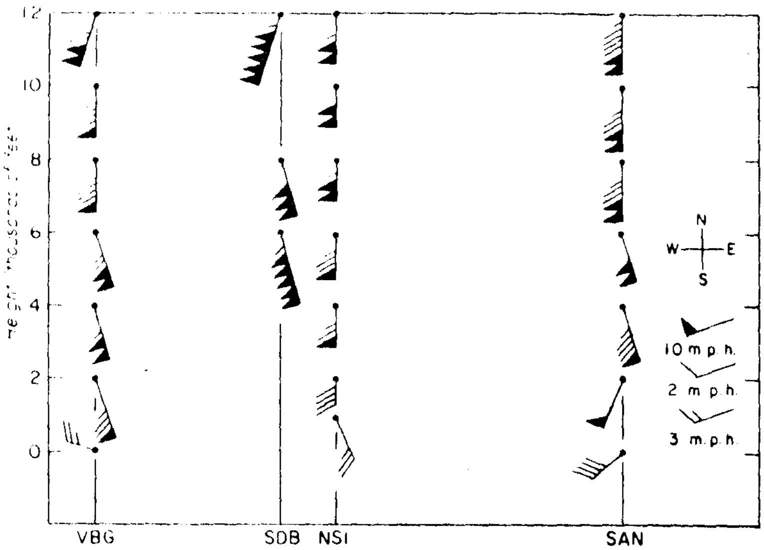


Figure 10–*Cross section of winds at 1100 P.d.s.t. on August 24, 1968 over Vandenburg AFB (VBG). Sandberg, California (SDB), San Nicholos Island (NSI) and San Diego (SAN).*

temperature at Azusa at 1100 was 89°F. and at 1200 was 94°F. A conservative estimate of 90°F. for the surface temperature at the fire and a similarly conservative estimate of dewpoint were used to construct the sounding. The sounding shows that little energy would be necessary to overcome the static stability in the fire area. In other words, existing atmospheric conditions were such that strong convection could easily be established by an outside influence such as heat source or wind movement.

Upper winds over southern California were southerly and relatively strong on August 24 *(fig. 10).* Streamline analyses of data from Los Angeles, Riverside, and San Bernardino County Air Pollution Control District stations and the Environmental Science Services Administration, Weather Bureau stations were made *(fig. 11).* The surface windflow at 0800 on August 24 was characterized by down-canyon and offshore flow *(fig. 12).* The only evidence of onshore flow (sea breeze) was in the Long Beach area of the Basin. By 0900 we see the sea breeze was evident all along the coast and downslope winds were decreasing as shown by the shift from northerly to easterly winds along the foothills *(fig. 13).* The sea breeze had reached the Azusa area for the first time on the 24th by 1000 *(fig. 14).*, retreated before 1100 as indicated by the east winds *(fig. 15),* then advanced into the Azusa area by the next hour, 1200, as shown by the flow pattern at that time *(fig. 16).* The sea breeze was very strong in all areas by 1200 and was becoming stronger by 1300 *(fig. 17).*

The surge of the sea breeze into Azusa as shown on the 1000 chart was probably onshore flow aloft surfacing because of instability and convective mixing due to surface warming. But this instability and warming was not sufficient to hold the sea breeze in the Azusa area so it retreated. It returned to stay when there was sufficient surface heating.

The closest reporting station to the disaster area was the Azusa Air Pollution Sampling Station located 2.7 miles to the west-southwest. The wind direction and speed record for that station shows that the sea breeze that was at Azusa at 1000 retreated at 1010 with the wind shift from southwesterly to easterly *(fig. 18).* At 1120 the winds shifted again to southwesterly as the sea breeze arrived again in the Azusa area. This same surge of the sea breeze most likely penetrated also into the disaster area and possibly caused the sudden change of wind direction and an increase of windspeed at the exact time (1124) the fire whirl developed. (The times on the record are P.s.t. so one hour must be added for P.d.s.t.)

Fire Weather Conditions

An analysis of the Fire Load Index (FLI) was made for August 21 through August 24. The FLI is an indication of the fire danger and is a function of fuel moisture, temperature, humidity, and windspeed. Observations contributing to FLI from four nearby stations are given in table 3. The FLI was low on the 21st and 22nd with Duarte and Eaton Canyons reporting 6 on both days; but the Santa Ana condition occurred on the 23rd, with a sharp rise in temperature and a drop in relative humidity. This caused a large rise in FLI. The Santa Ana condition was gone by the 24th; however, the effects were still

Table .3. – *Fire weather observations before and daring the Canyon Fire*

Date (1968)	Dry bulb.	Wet bulb	Dew - point	Rel. humidity	Stick moisture	Wind direction	Wind speed	Fire load index
	ºF.	*ºF.*	*ºF.*	*Pct.*	*Pct.*		*M.p.h.*	
	PADUA HILLS, ELEVATION 1,810 FEET, 1330 P.D.S.T.							
8/21	75	57	43	31	9.0	SW	10	10
8/22	77	58	43	30	9.0	SW	12	14
8/23	93	58	20	7	6.0	S	8	18
8/24	–	–	–	–	–	–	–	–
	EATON CANYON, ELEVATION 975 FEET, 1330 P.D.S.T.							
8/21	77	58	43	30	7.0	SE	6	6
8/22	82	64	53	37	7.0	S	6	6
8/23	95	62	35	12	5.0	SE	10	31
8/24	94	63	40	15	5.0	E	8	20
	DUARTE ELEVATION 580 FEET, 1430 P.D.S.T.							
8/21	79	60	46	32	6.0	SW	4	6
8/22	82	62	49	31	7.0	SW	5	6
8/23	98	64	38	13	[1]4.5	SE	10	131
8/24	96	62	34	11	4.0	SW	7	26
	IRVINE LAKE, ELEVATION 970 FEET, 1430 P.D.S.T.							
8/21	73	58	47	40	9.0	SW	12	10
8/22	76	63	55	49	9.0	SW	5	3
8/23	94	60	28	10	5.5	W	10	29
8/24	86	64	50	29	5.0	W	9	10

[1] Estimated

Table 4–*1968 precipitation data for stations near the disaster area*[1]

Month, day	Glendora West	Azusa City Park	Rogers Canyon
		Inches	
January	1.48	1.35	1.39
February	1.71	.62	1.53
March	3.72	4.16	3.97
April	.92	.68	1.09
May	.06	(2)	.31
June	.18	.10	.09
July	.03	.02	(2)
August 7th	.01	.20	.10
17th	.02	(2)	.03
20th	(2)	–	–
Total[3]	8.13	7.13	8.51

[1] Glendora West is 1.5 miles southeast of the disaster area; Azusa Park is 1.8 miles southwest; and Rogers Canyon is 1.6 miles west-northwest.
[2] Trace.
[3] To August 25, 1968.

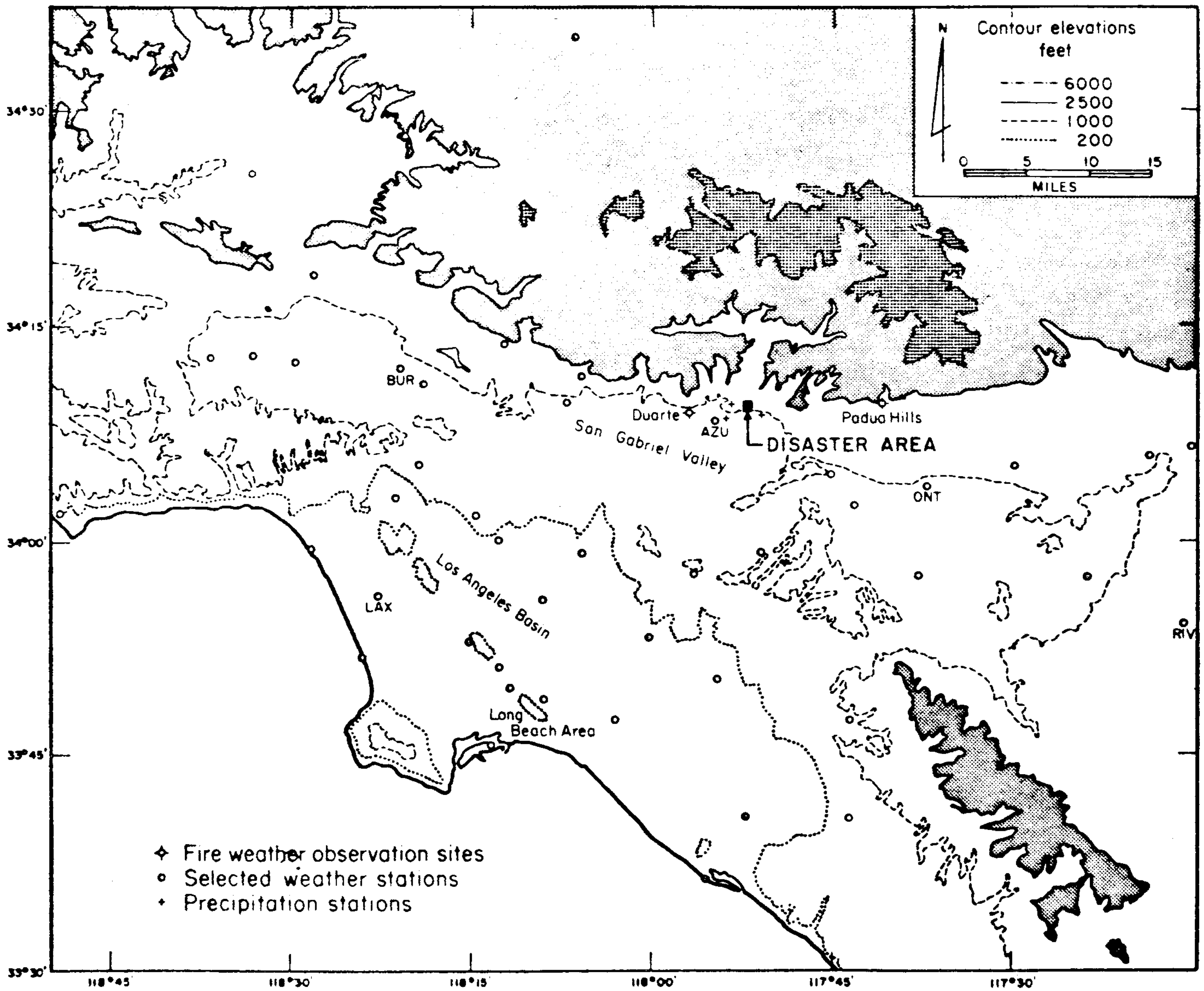


Figure 11.—*Location of data stations and disaster area.*

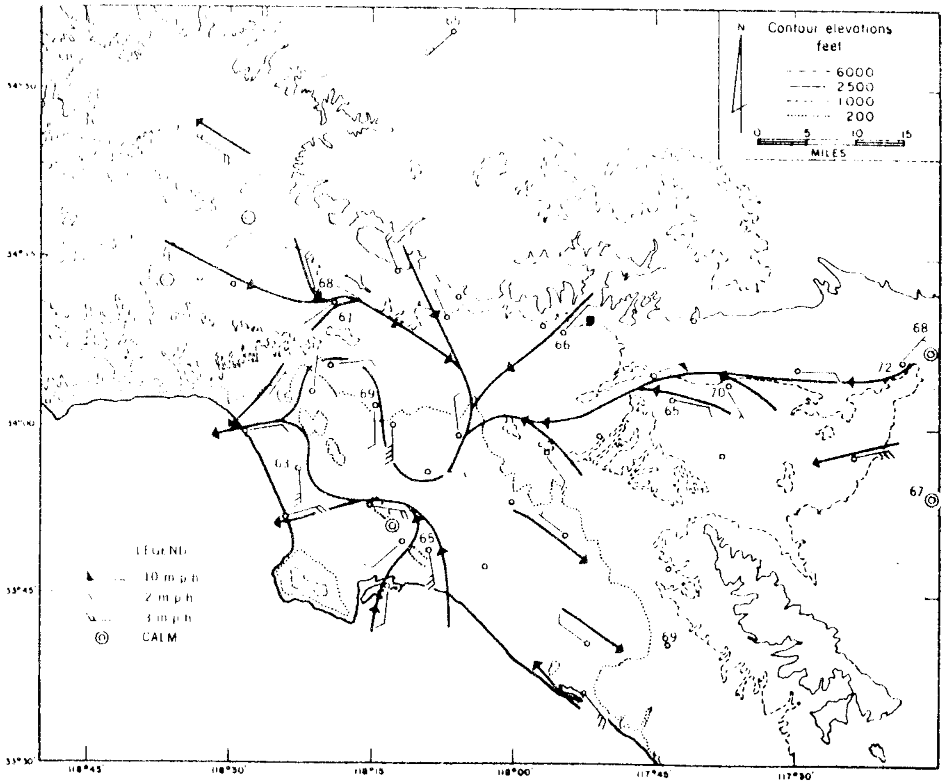


Figure 12.–*Streamline analysis for Los Angeles Basin at 0800 local, August 24, 1968. Temperatures are plotted above the station.*

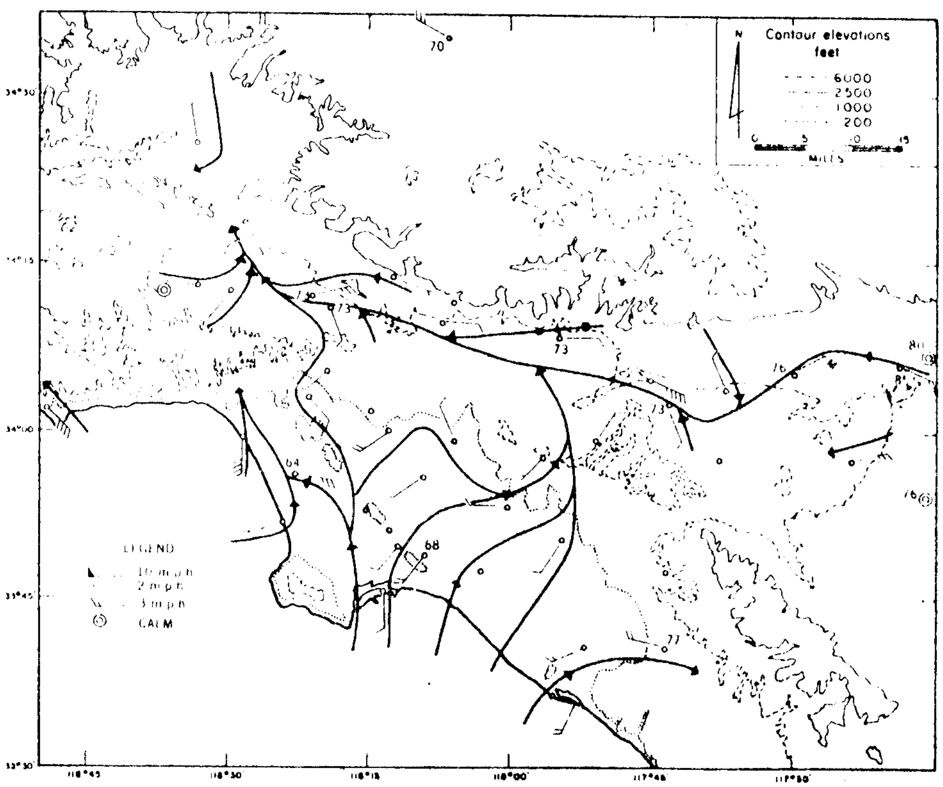


Figure 13.–*Streamline analysis for Los Angeles Basin at 0900 local, August 24, 1968. Temperatures are plotted above the station.*

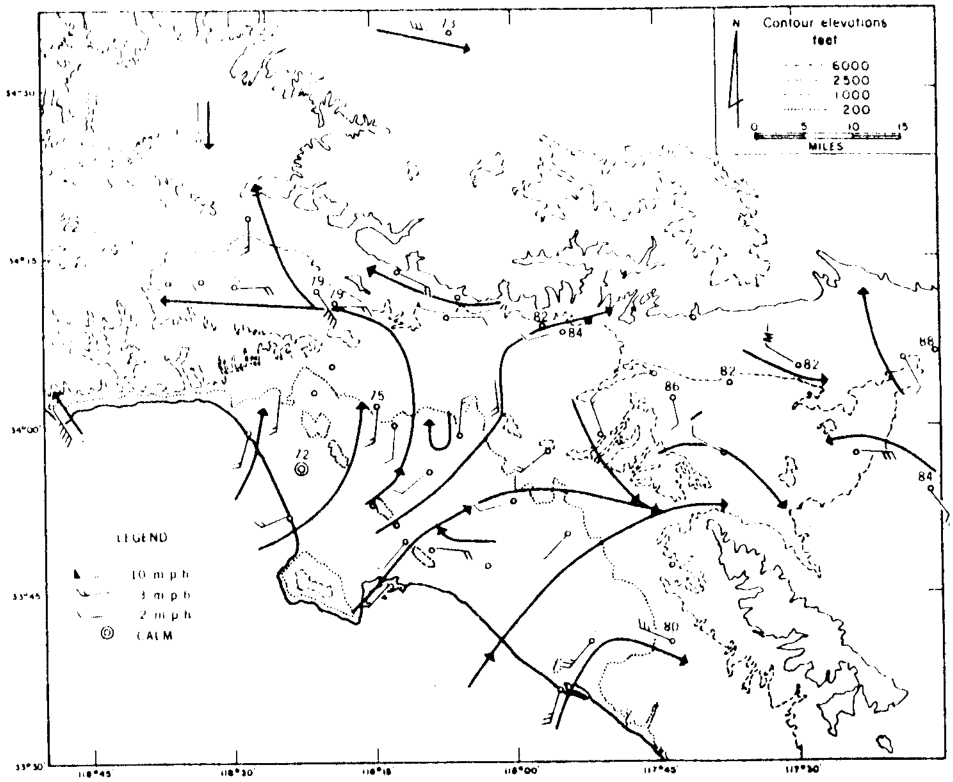


Figure 14.–*Streamline analysis for Los Angeles Basin at 1000 local, August 24, 1968. Temperatures are plotted above the station.*

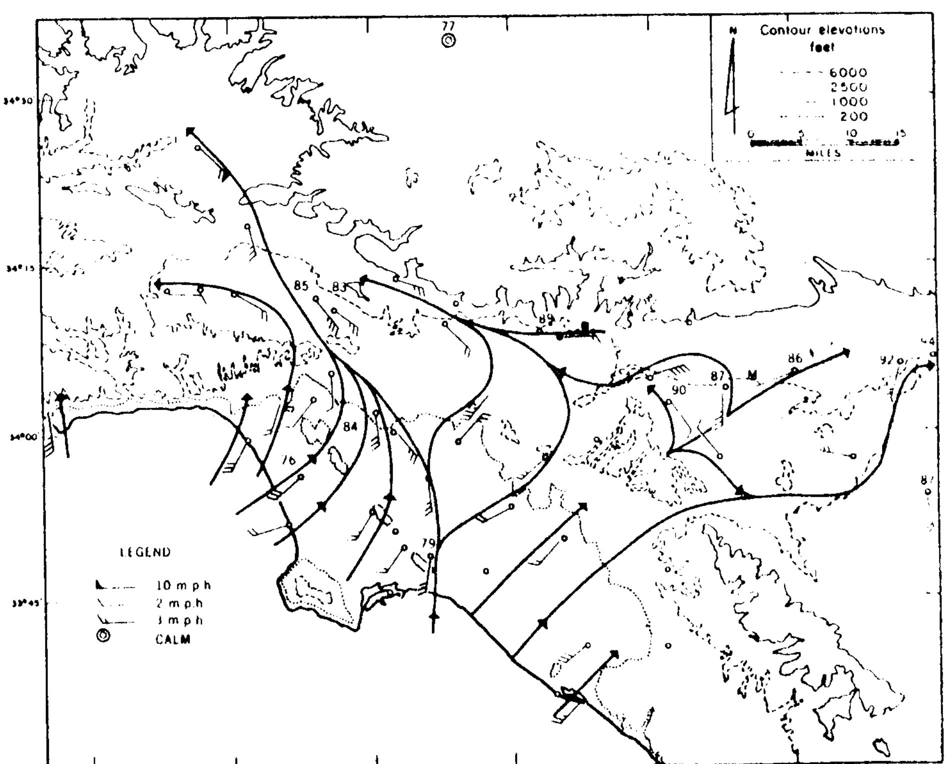


Figure 15.–*Streamline analysis for Los Angeles Basin at 1100 local. August 24, 1968. Temperatures are plotted above the station.*

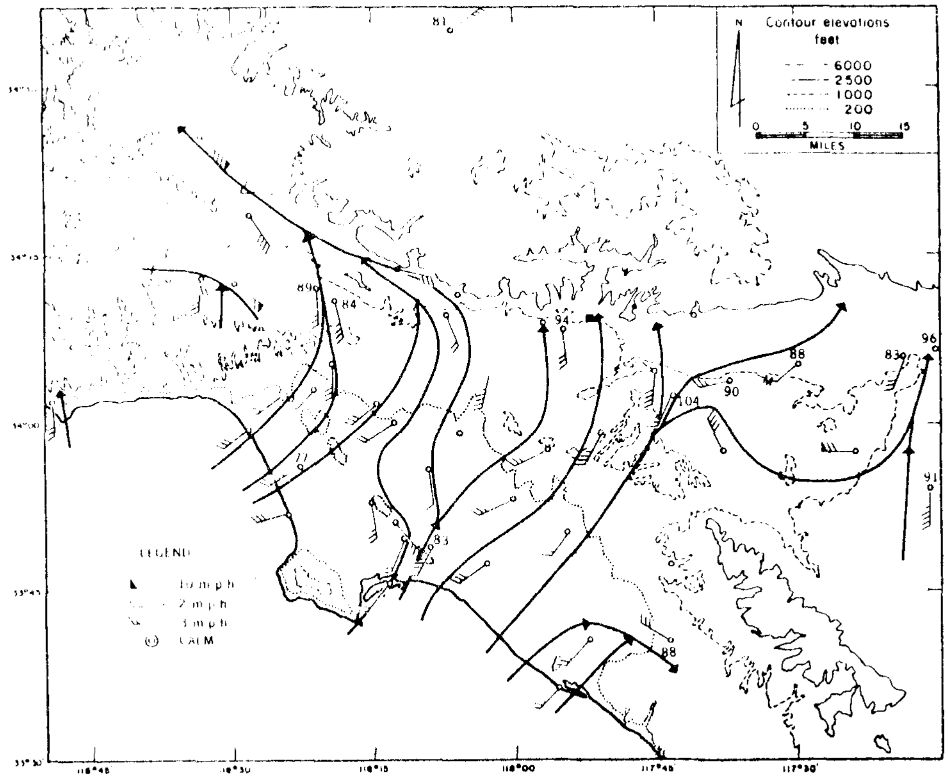


Figure 16.–*Streamline analysis for Los Angeles Basin at 1200 local, August 24, 1968. Temperatures are plotted above the station.*

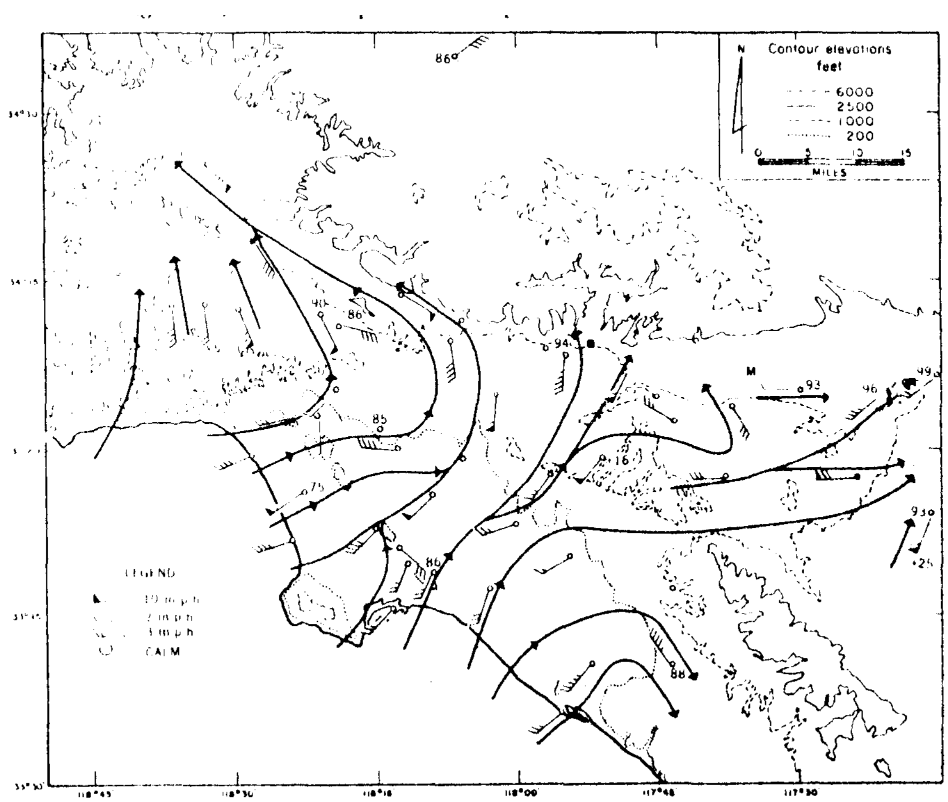


Figure 17.–*Streamline analysis for Los Angeles Basin at 1300 local, August 24, 1968. Temperatures are plotted above the station.*

felt in the disaster area as evidenced by the observations at Duarte, only 4 miles to the west.

Lack of precipitation contributed strongly, of course, to the high FLI. The last rain occurred in the area on August 17 *(table 4)*, but this was very light. The last significant rainfall occurred in April.

FUELS ANALYSIS

The driving force of any wildland fire is of course the energy provided by the particular combination of fuels present. Therefore, characteristics such as fuel size, loading, moisture content, heating value, and fuel bed compactness are of prime importance in analyzing fire behavior.

Fuel Types

The chief chaparral fuels at the disaster site on the Canyon Fire were sumac, scrub oak, chamise, and sagebrush, but a few sycamores and introduced shrubs and trees which apparently originated from landscape plantings in nearby residential areas, were scattered throughout. A dense stand of grass and other herbaceous vegetation grew in association with chamise, and sagebrush in the more open places.

The last major fire in this general area was in 1919. Local residents indicated, however, that some areas in the Canyon Fire had not been burned for 70 years or more. The disaster site was probably one of these. Because of the age of the cover, many years of low rainfall, and smog damage, there was a heavy accumulation of litter and a large amount of dead material in the standing fuel. Unburned fuel *(figs. 19, 20)* near

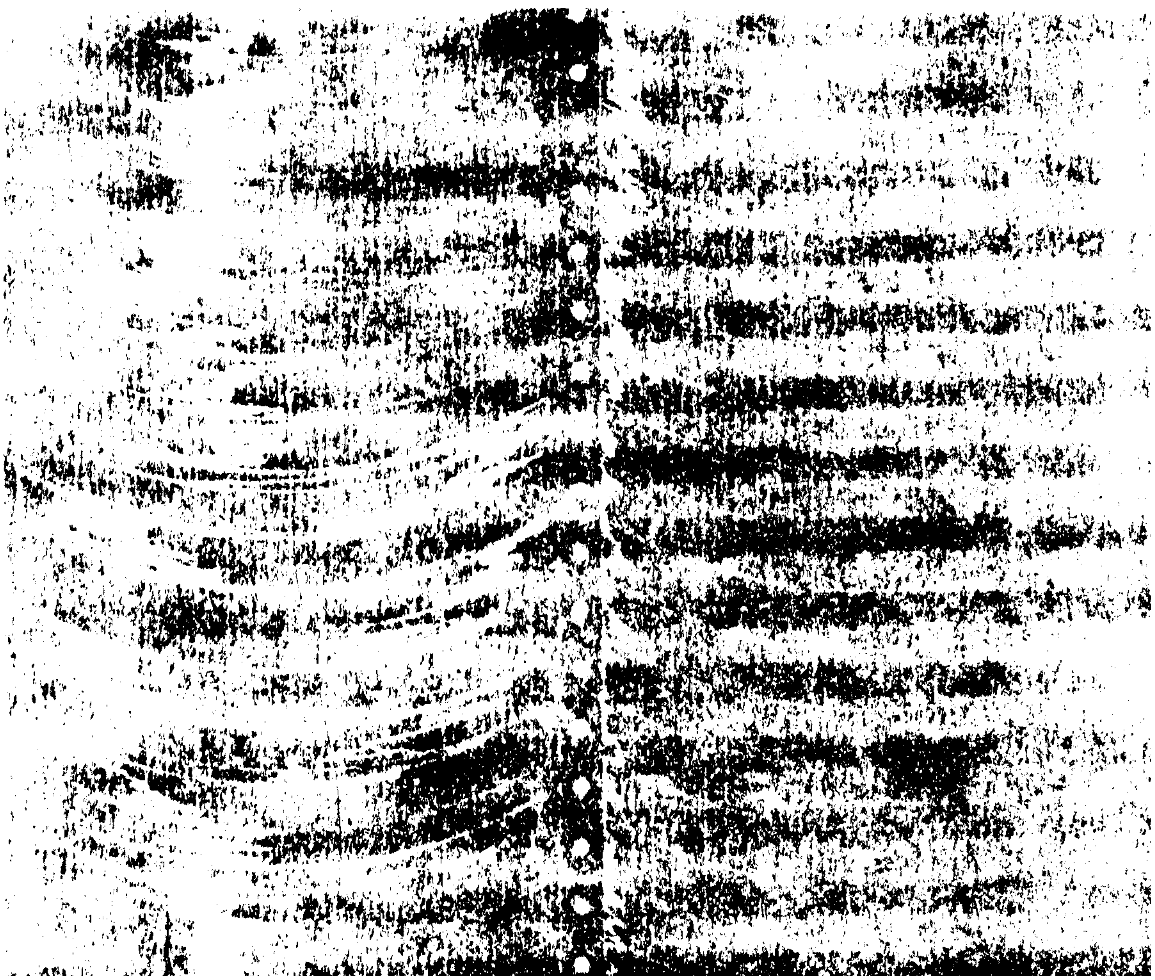


Figure 18.–*Wind speed and direction record for the Azusa Air Pollution Sampling Station. The times are P.s.t.*

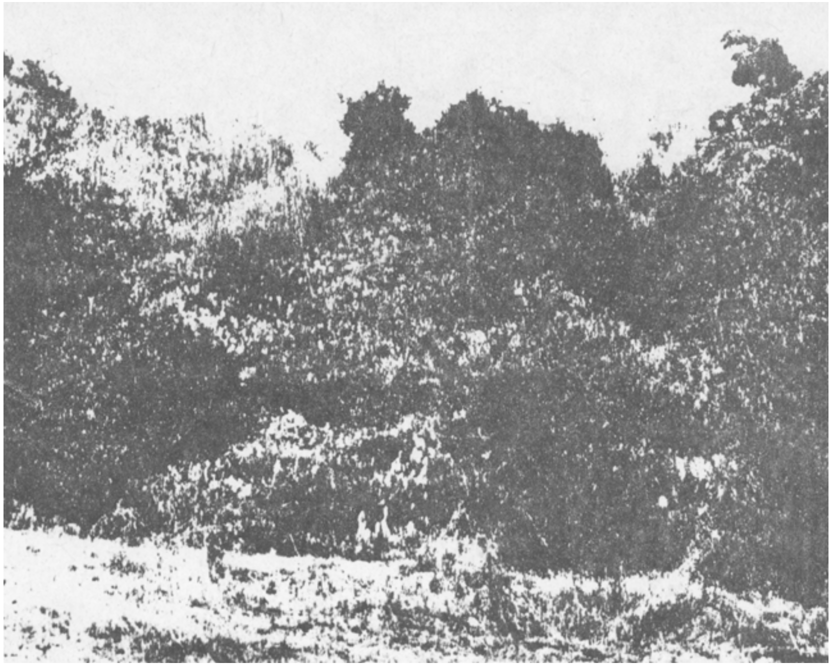


Figure 19.–*Characteristic fuel of the fire accident area.*

the fire area is believed typical of fuel conditions at the disaster site.

Fuel Moisture

The moisture content of the fuel strongly influences the speed with which the fuel burns and hence the rate of release of its potential thermal energy. Fuel moisture samples taken from living plants near the fire area a few hours after the accident indicated sagebrush leaves had a moisture content of 131 percent, scrub oak leaves 79 percent, and chamise leaves 63 percent. These moisture contents are about normal for the season of the year and arc low enough so that the foliage and small limbs can contribute substantially to the heat production of the burning fuel.

The moisture content of the dead fuels is highly dependent on the relative humidity and fuel temperature. Samples of scrub oak deadwood had a moisture content of 5.1 percent. This value is consistent with the relative humidity and temperature for August 24, and very close to the value determined at nearby fire weather stations. Although not extremely low, it is well within the range where fuels will burn hot and fast.

Figure 20. –*Heavy ground fuel typical of fire accident area.*

Fuel Loading

Except under very extreme conditions chaparral fuels seldom burn up completely. The smaller dead and live stems, foliage, and surface fuels burn first, creating the thermal pulse peak and the long flames

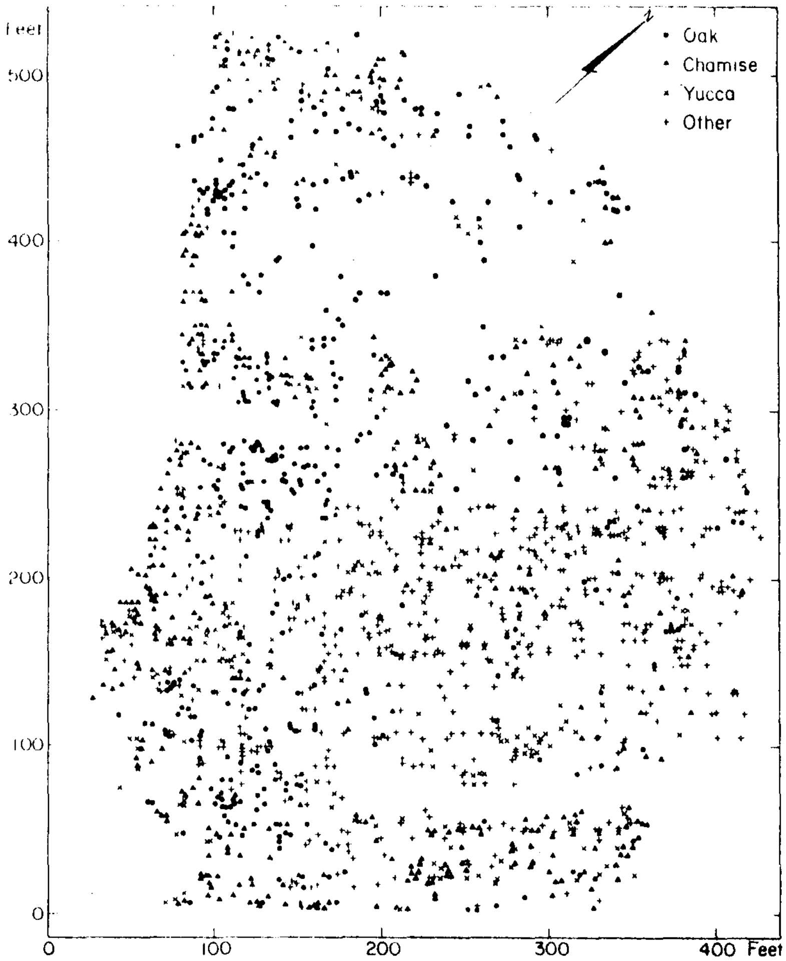


Figure 21.—*Fuel remnant location map for accident ravine. Map shows plant locations, not area.*

that carry the fire into unburned fuel. The larger fuels burn later or not at all. To provide an estimate of the fuels that actually burned, the ravine in which the men were trapped was divided into 25-foot-wide horizontal strips. The location of each plant within each strip was plotted on a map and an estimate was made of the proportion of the plant that had burned. The resulting map also showed the vegetation density *(fig. 21).*

For the predominant species, typical fuel loadings and proportion of dead material for fuels of the height and density of those in the fire area were: [3]

	Lb./sq. ft.	Percent dead
Species:		
Scrub Oak	1.06	20
Sumac	1.06	20
Sagebrush	.28	50
Chamise	.28	35
Grass	.18	100

[3] Derived from Operation Firestop data.

Under the scrub oak and sumac the ground fuel and litter was estimated at 1.01 lb./sq. ft., and under the chamise and sagebrush, 0.26 lb./sq. ft. In the open areas between shrub fuel patches the herbaceous fuel loading was estimated to be 0.18 lb./sq. ft.

Fuel Heating Values

The heating values of woody material in chaparral fuels do not vary greatly among species. The heating value of the foliage, however, is usually somewhat higher than that of the wood. Table 5 lists typical values for the predominant species in the fire area.

Table 5.–*Heating values of selected chaparral species*

Species	Wood	Foliage
	B.T.U./lb	
Scrub oak	8,050	8,766
Sumac	8.228	8,873
Sagebrush	8,213	9.652
Chamise	8,411	9,431

Heat Production

The fuel that contributed directly to the fire run that killed the Camp 4-4 crew was in areas B and C *(fig. 22).* Area B was covered principally with scrub oak and sumac and a deep layer of litter. Grass grew in the more open areas. Chief fuel in area C was chamise and sagebrush along with a dense stand of grass and other herbaceous vegetation. Surface area of B was 22,326 sq. ft.; of C, 1,586 sq. ft.

Total fuel that burned in area B is estimated at 30,810 lb. and in area C at 1,460 lb. Total fuel in the two areas was thus 32,270 lb., or about 1.35 lb./sq. ft. Assuming a heating value of 8,300 B.t.u./lb., the total heat production for the two areas would be about 261,841,000 B.t.u., or 11,201 B.t.u./ sq. ft. Burning time for the fuels would be 4 to 5 minutes. However, about 65 percent of the fuel could be expected to burn in the first 30 seconds. This would give a heat production rate of 14,561 B.t.u./sq. ft. per minute. With fuels burning at this rate, combustion zone temperatures in the order of 2500°F. would be likely.

FIRE BEHAVIOR

In the earlier section on weather, we had reported that wind speeds during the morning of August 24 were variable. In the disaster area they were very light -estimated at 2 to 4 miles per hour by firemen at the site. Under these conditions the fire behavior was almost entirely controlled by the topography.

Topography-Dominated Fire Behavior

Topography-dominated fire behavior has certain well defined characteristics. Where the fire is backing down a steep slope, as it was on Glendora Ridge, the fire spread is frequently slow and intermittent. The fire moves along one fuel element to the next and initially may burn only the more compact fuels near the ground surface. in steep topography, fire spread is speeded by burning material rolling down the slopes, igniting other fuel as it goes. Flying firebrands from flareups may also scatter fire over a wider area.

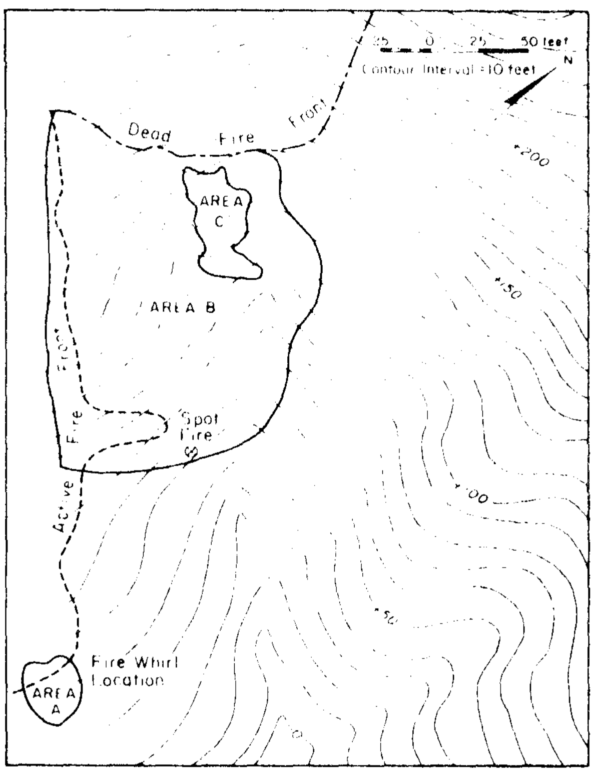


Figure 22.–*Topographic map of accident ravine.*

In steep V-shaped ravines the fire tends to progress most rapidly down the bottom of the ravine since rolling material tends to collect there. Once the fire becomes established in the bottom of the ravine, fuel then becomes available upslope from the fire along the ravine sides, and a series of fire runs up the slope and up the ravine can develop. The fire front in a ravine then soon assumes a V shape with the apex of the V pointed down slope. The upslope fire runs often carry over the rim of the ravine and provide a source of rolling firebrands to spread fire into the bottom of the next ravine. These hot fire runs also provide the necessary convection and turbulence to carry firebrands into unburned fuel.

When the fire front can move laterally as well as downslope, the fire runs tend to become longer and more intense. As the fire progresses down one ravine the probability becomes greater that a fire run up the ravine side will establish fire in an adjacent unburned ravine. Then extensive areas of fuel above the fire become available and a long fire run is possible.

During the daytime natural thermal convection plays an important role in the behavior of a fire, particularly for slopes with a southerly aspect. Because of unequal solar heating, convection currents are stronger in the ravines than over the slope as a whole. These air currents aid in the early development of the fire in the ravine bottom. Once a fire run starts, the added heat from the fire increases the natural convective flow and the fire is pushed faster and faster as its flaming area increases. Because of the slope and convective air flow, the flames are held close to the fuel and there is efficient flame contact and fuel preheating. When the fire reaches the top of the ravine wall or the head of the ravine, the convective flow slackens and progress slows until the fire works its way into a favorable position of fuel and topography for another run.

Between runs, progress of a fire down the slope is often very slow. Because of the upslope thermal currents the flames are bent away from unburned fuel. The thermal currents also tend to cool the standing fuels and prevent their ignition by radiated heat. Downward movement of the fire is thus primarily in the surface fuels, and the fire may move for a considerable distance downslope without igniting the standing fuel. However, there is usually a delicate balance here, particularly in chaparral fuels. A gust of wind, a concentration of surface fuel, or a low-growing shrub can result in one shrub "crowning out." When this happens, adjacent shrubs are immediately in the flame zone and a fire run or "flareup" is triggered. In dry fuels, on steep slopes, and under strong solar heating these flareups can develop very quickly and move with great speed. Rates of spread of 6 to 10 ft./sec. are common and spread rates as great as 100 ft./sec. for short distances under extreme conditions have been noted.

Fire Behavior in Disaster Area

The fire run that trapped the Camp 4-4 crew was similar to numerous runs that had occurred on Glendora Ridge previous to the accident. By 0830, fire in the adjacent ravine had already begun to move downslope in the typical V-shaped pattern. Fire had also slopped over the rim at the upper edge of the ravine in which the crew was working. Additional fire runs up the wall of the adjacent ravine increased the amount of fire at the rim of the accident ravine. Water drops by a helicopter slowed the spread of the fire but failed to check it entirely. By 1100 the fire had burned over the rim for a considerable distance down from the head of the ravine and, at the lower end of the slopover, was burning briskly and moving down into the ravine *(figs. 22, 23).* At about 1124 a patch of sumac and scrub oak in this area crowned out suddenly. A fire whirl quickly formed over the hotly burning brush patch *(fig. 22, 24).* It appears likely that a firebrand from this whirl moved downslope and established fire well down into the ravine and below the crew *(figs. 22 and 25).* This fire crowned immediately and ran up the ravine and over the crew *(fig. 26).* Probably not more than a minute elapsed from the time the fire whirl developed and the time fire became established below the Camp 4-4 crew. It is likely the fire run that trapped and killed the crew reached the head of the ravine in 30 seconds or less.

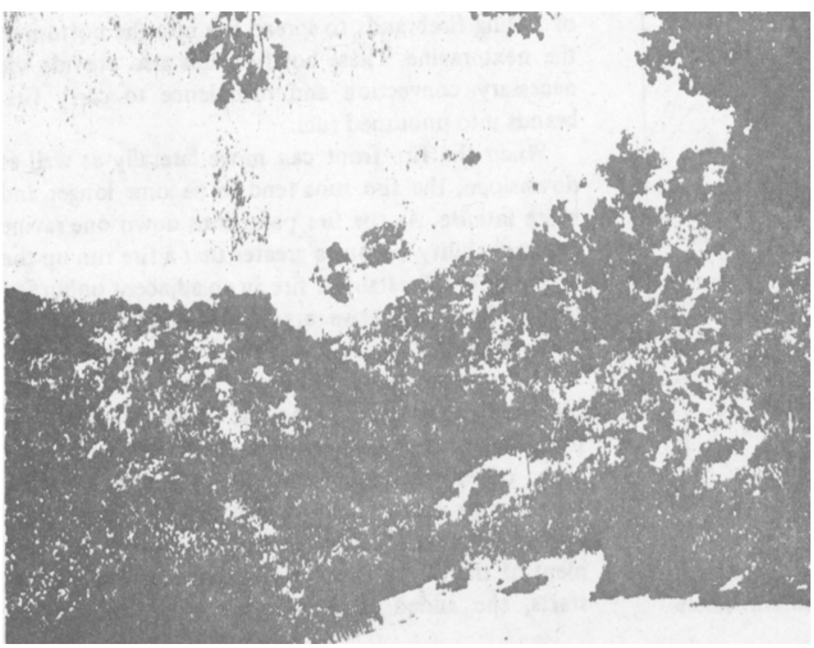


Figure 23.–*Fire front at about 1100 hours on August 24.*

Figure 24.– *Fire whirl believed responsible for establishing fire below crew.*

Because of the steep slopes and strong convective currents, the flames were held close to the ground so that the crew was subjected to maximum temperatures. It is likely that the fire front was preceded by a wave of hot combustion products high in carbon monoxide and carbon dioxide and low in oxygen.

The chief difference between the fire runs that trapped the crew and previous fire runs on the Canyon Fire was the appearance of the fire whirl. Fire whirls had not been observed previously by the firefighters on the line. Although fire whirls frequently appear on the lee side of ridge tops, their development in this area is usually restricted to

Figure 25. –*Spot fire (upper right) below crew location. Note remnants of fire whirl still visible at upper left.*

Figure 26. –*Beginning of fire run that trapped crew. Crew location is to left and above point of highest flame.*

conditions of moderate air flow or to areas where natural eddies or vorticity appears. It thus appears probable that the fire whirl was caused by a sudden and local increase in air flow. The increase in fire activity all along the slopover area tends to bear this out. Increasing air instability resulting from warming of the surface air layer as the day progressed also probably aided in the whirl development.

The increase in speed of the local air flow may have resulted from the sea-breeze front reaching the fire area. It also may have been caused by the turbulence created by the low-level passage of an air tanker through the area just before the fire flareup. Both of these potential causes may have combined to increase the air flow and turbulence. Data available do not permit us to pinpoint the exact cause.

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