HUELVA FATALITIES. ALAJAR FOREST FIRE. JUNE 30, 1999: DESCRIPTION OF THE EXPLOSIVE PHENOMENON THAT CAUSED THE DEATH OF FOUR ANDALUCIA FIREFIGHTERS

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1.- Abstract.

A description of multiple situations that expose firefighters to danger, and methods for detecting circumstances where the rules of safety do not apply are presented. Sometimes it is difficult to follow all the variables impacting the behavior of the fire, often this is linked to changes in the influencing variables that are difficult to sense. Such conditions can result in conflagrations that drastically alter the fire propagation rates. These changes can occur fast enough that firefighters are unable to reach positions of safety. This article describes phenomenon responsible for the dynamic and high intensity fire explosion that trapped four firefighters from Andalusia (Plan Infoca).

Keywords:Thermal inversion. Plume convection. Atmospheric low pressure. Crown fire. Spread acceleration. Forest fuel model.

2.- Analysis of the dynamic and energy behavior of the fire.

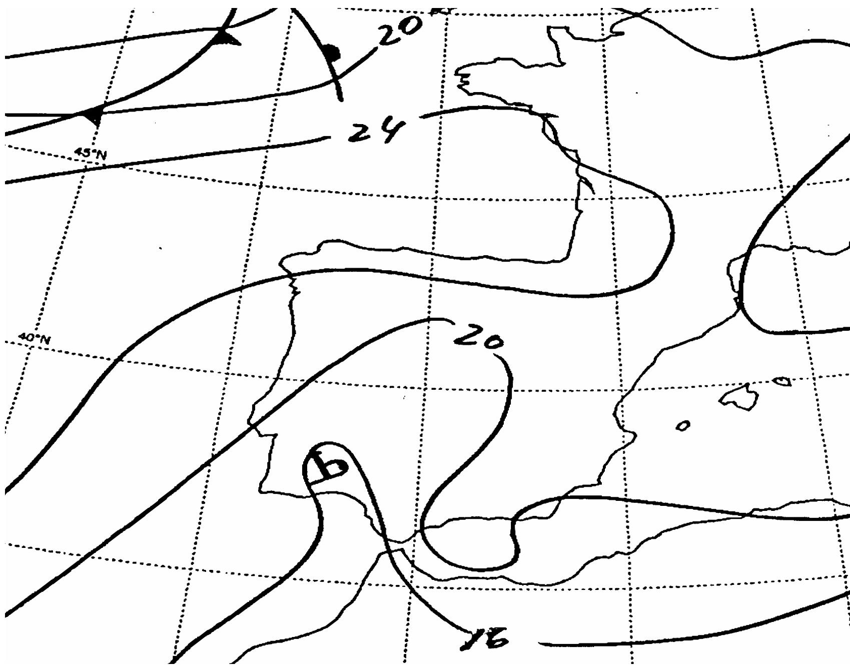
To approach the study of the explosive phenomenon that motivated the surprising behavior of the fire happened in the municipality term of Alájar the day 30 June of 1999, it is necessary to define the state of each one of the factors that govern the physical and chemical process of the combustion associated with the propagation of the fire. For this it is necessary to study the phenomenon of combustion and the conditions responsible for the propagation. That is to say, the meteorological state, the biggest or smaller combustibility of biomass and the direct influence of the topography of the area. Said in another way, all fire behavior, is a consequence of the individual contribution of the three previously defined agents. The content of the present analysis has been structured according to the following index:

3.1. - definition of the meteorological state
3.2. - characterization of the forest fuels present
3.3. - topographical aspect
3.4. - description of the behavior of the fire

3.1. - Definition of the meteorological state

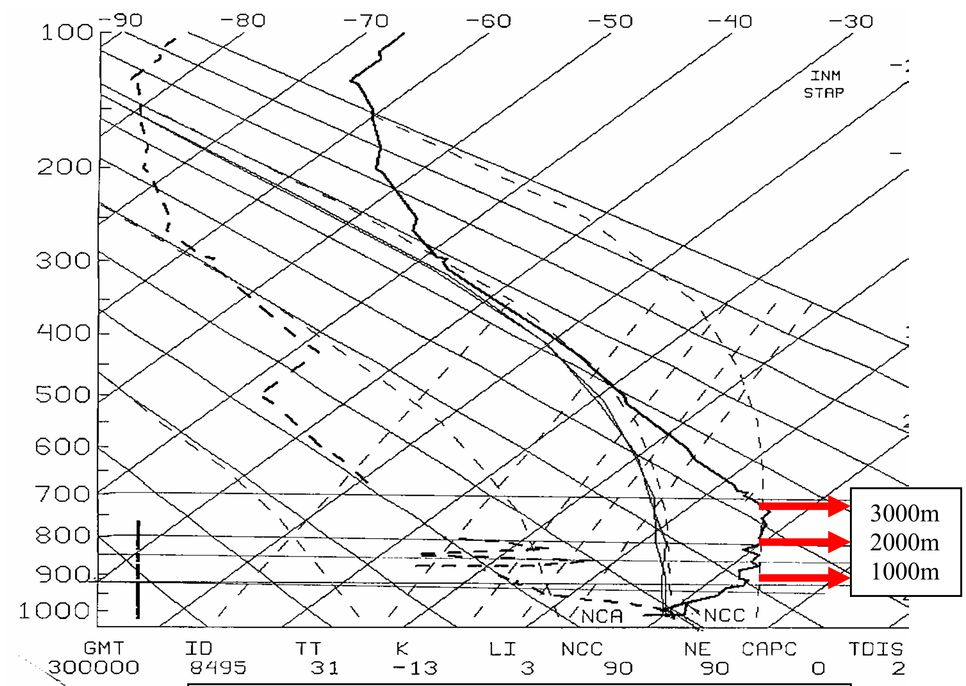
The influence of the meteorology is decisive not only for the direct effect on the propagation and evolution of the fire in the forest fires, but also for ignition. The influence of the meteorology at the local level is not only a consequence of convective phenomenon, resulting from differential soil heatings, but also of the synoptic meteorological conditions. Therefore it is necessary to know the vertical profiles of temperature in the atmosphere and the behavior of the different parameters, that is, temperature, relative humidity, speed and wind direction. This information is need for the days preceding the accident as well as during the same day of accident.

- With the meteorological surface maps made by the the National Institute of Meteorology (Center of Western Andalusia), one can observe the formation of a micro instability center, during the previous days and during the day of beginning of the fire low atmospheric stability and consequently with the influence of discharges pressures. These micro instability centers constitute centers of low pressures that are responsible for upward currents of the masses of airs. For the day June 30, the 1016 mb level, rather deep that open it covers in a diagonal way the Southwest area of the Region, with the influence on, the area of the fire. Besides being responsible to local level of the ascendant vertical currents, it is identified with the permanency of a great mass of hot air in their vertical profile.

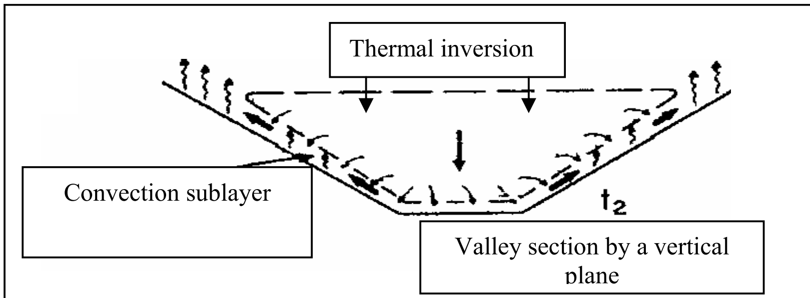


Surface level pressures analysis for 12:00Z
of 06/30/1999

- With the atmospheric stability is presented along the thermal profile, a widespread investment state from the superficial level to above the three thousand meters, such a situation stays in the polls made from Gibraltar Meteorological Station to the 00Z and the 06Z. This information is valid for a thousand meters up in the area above the fire. The effect of the instability at superficial level is alterations in the thermal inversion distribution in the lower levels. This indicates that the derived thermal inversion from the orographic influence don't consolidate completely, and consequently the thermal belt (inversion layer top) when not being sufficiently fixed in the hillsides allows for the agitation of the convective wind (up and down winds slope). This circumstance implies fragility in the permanency of the thermal inversion. Such a circumstance happened the day of the origin of the fire.



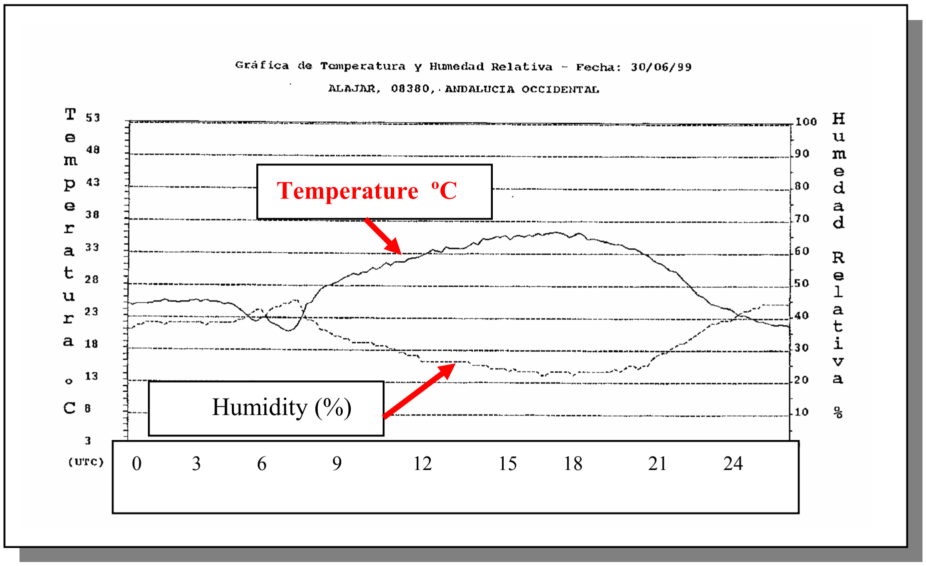
Gibraltar Meteorological Station data base, 00Z
Atmosphere thermal inversion high level



- In relation to the directly identified local conditions with the area of Alájar, it's possible to observe in the enclosed graphics the temperature and relative humidity. The values shown are characteristic of very dangerous conditions ((above the 31ºC, humidity relative below 30%). From this point of view of the origin and propagation of the forest fires when the conditions are of the level "30",is complicated fire behavior associated with difficult suppression.

Hour (sun)	TEMPERATURE	HUMIDITY %
10:30	32	28
11:00	33.5	26
11:30	34	26
12:00	33.8	26

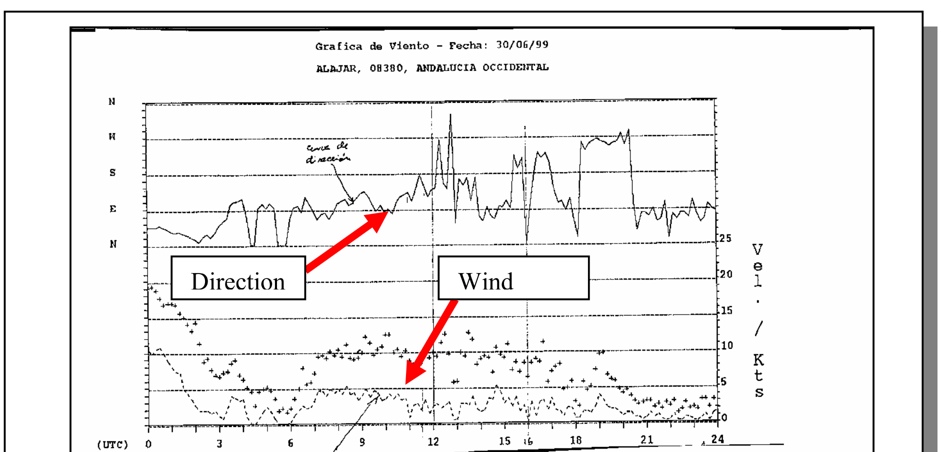
Weather Alajar Station data base 06/30/1999



The behavior of the wind in intensity and direction, is manifested with low to very low values and with directional permanency of origin. Such a circumstance lessens the aggressiveness manifested by the temperature and the relative humidity.

HOUR (sun)	WIND DIRECTION (degree)	V (KM/H.)
11:00	126	1.8
11:05	118	2.88
11:10	109	3.96
11:15	104	5.04
11:20	145	4.68
11:25	165	4.24
11:30	180	3.6
11:35	155	4.68
11:40	148	5.4
11:50	138	2.7
12:00	135	3.96

Direction and wind speed data base. Alájar weather station. 06/30/1999



1 nudo= 1kts=0.5 m/seg. (+). máx. wind speed in 10 minutes

3.2. - Characterization of the forest fuels present

The spatial distribution of the live and dead vegetation indicates the combustibility from the point of view of the energy evolution and propagation of the fire. Fuels in the forest area have been classified according to the Behave classification (Anderson 1982) into the following fuel model types:

- Model 5 (Behave system)

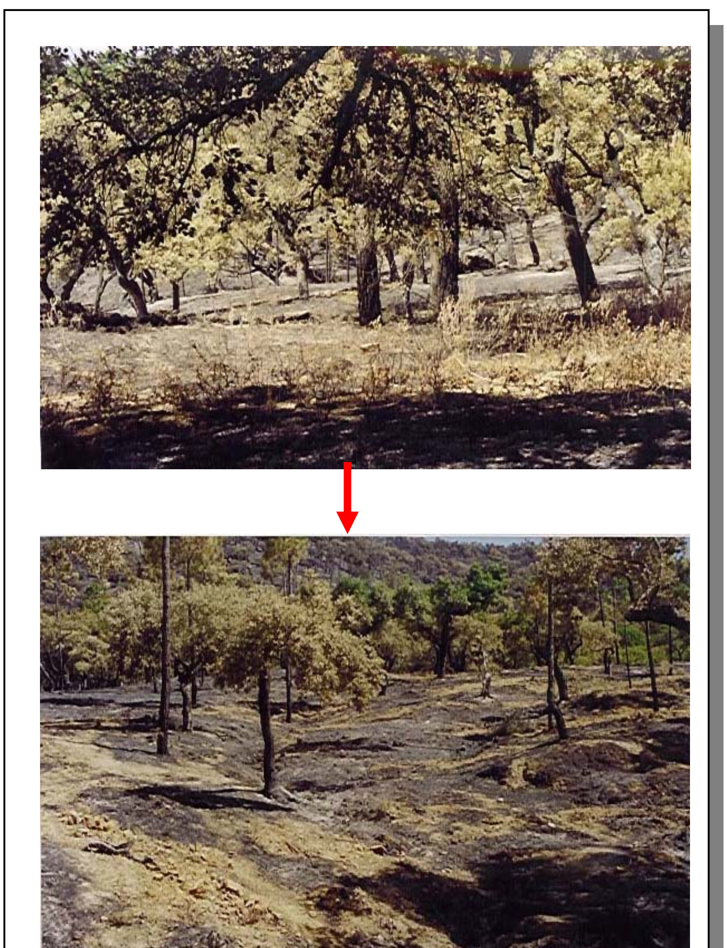
Dense shrub, height less than 0.6 meters with light loads of surface fuels of the same shrub that contribute to spread of the fire with low wind speed. The fire generally moves through the superficial fuels that are integrated with litter spread by the heath, grass and other herbaceous of the surface fuels. The fires are not very intense because the loads of fuel are low, the fuel loads estimated, is 6 to 9 Tm/ha.

- Model 4. -

Shrubs or tree-lined young very dense vegetation about two meters high. Horizontal and vertical continuity of the fuel. Abundance of dead woody fuel (branches) on the live plants. The fire spreads quickly with great intensity and big flames. The moisture of the live fuel has great influence on the behavior of the fire. The height of the vegetation depends on the local conditions. The loads of fuel is, 24 to 36 Tm/ha.

- Model 7. -

Inflammable shrubs 0,6 to 2 meters high that spreads the fire under the tree crown one. The fire is developed with higher contents of humidity of the dead fuel. The loads of fuel is , 8 to 15 Tm/ha.



Model resulting for mixed composition of model 4 and 7

Very high level of damage after fire evolution on resulting model M_r

- Model Mr. -

With the blended space distribution of the models previously defined 4 and 7, it has been necessary to formulate a custom fuel model. This model is responsible for the behavior of the fire. The distribution between the two models has been of 85% for the fuel model 4 and of 15% for the fuel model 7. The final load of resulting fuel model is 20 to 28 Tm/ha.

3.3. - Topographical aspect

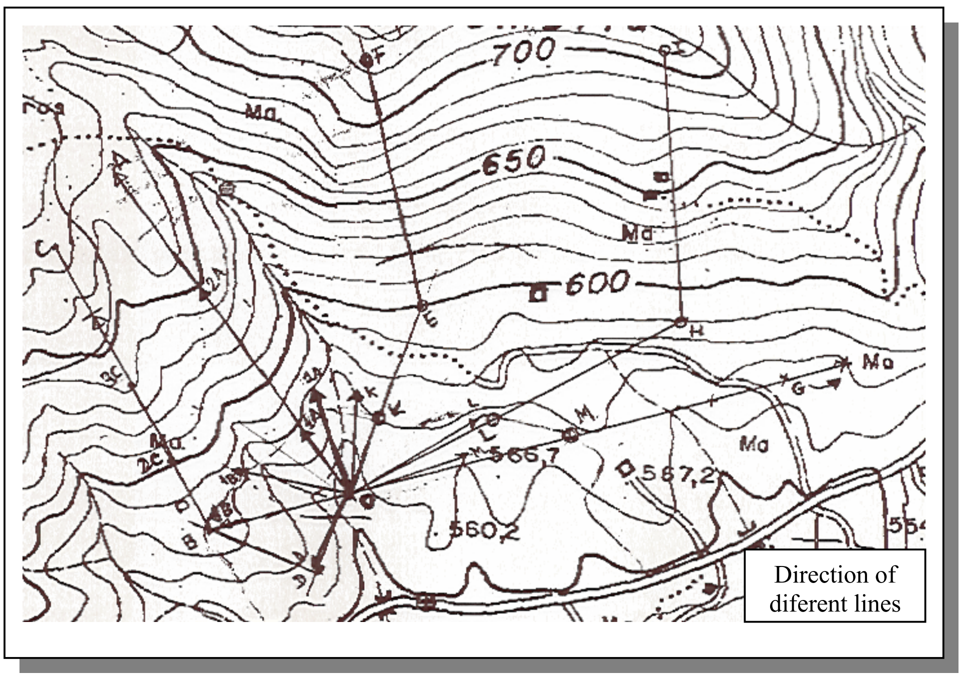
The scene of the events, is described from the topographical point of view, as a valley wrapped by a group of hills that are crowning each one of the mountains. The valley is 510 meters above sea level, located to the south of the regional road between “Alájar” and “Santa Ana la Real”. The distribution of the mountains is the following: in the northwest area sierra is “Los Cuchareros”, to the north “La Umbría” in whose south aspect hillsides were where the fire was ignited, to the east of the center of the valley “La Sierra Camposanto”, to the southeast “La Sierra Giralda” and to the southwest the “Sierra de las Cumbres”.

This conformation facilitates the atmospheric stability situations. The stagnation of the layers of air that for convectives phenomenon associated to the differential heatings of hillside determines with the beginning of the sunset, the stratified formation of the masses of air that contained among the hillsides of the valley. The air masses form according to the vertical thermal differences, being a layer of air with higher temperature between two layers of lower temperature, the lowere one in contact with the bottom of the valley and the higher in contact free with the upper strata of the atmosphere. Such a situation defines the existence of a thermal inversion, located approximately to 650 meters of altitude.

The presence on the area of a local center of low pressure, resulted in instability, it determined the ascendant currents of the air propitiated by this, hinder a firm stratification of the thermal layers of the inversion, with a fragility situation, and consequently of easy rupture for heating effects.

The characterization and physiognomy of the hillsidewhere the fire developed is described by the composition of two hillside. The first one with east aspect and a narrow canyon or small ravine, and the second hillside with south aspect ends up uniting with the first one by means of a ravine of more depth and that in difference with the previously suitable one. If it reaches the superior hillside denominated "La Umbría". From the bottom of the valley (510 m) until the superior part of the affected hillside a difference of altitude of 210 meters exists. The distribution of slopes is included in the following chart according to the predominant direction of the propagation of the fire and from the origin point located to an altitude of 556 meters.

LINE (m.)	SLOPE (%)	LINE (m.)	SLOPE (%)	LINE (m.)	SLOPE (%)
(0 – 1 A) (87.5)	26.6	(B – 2) C (75)	21.33	(0 – K) (85)	16.47
(0 – 1 B) (145)	20	(2 C – 3 C)(87.5)	45	(0 – L) (170)	7.05
(0 – D) (137.5)	10.28	(3 C – C) (176.5)	19.83	(0 – M) (225)	4.44
(0 – E) (210)	20.9	(2 A – A) (150)	12	(K – E) (130)	23.76
(0 – H) (370)	9.18	(E – F) (265)	46.03	(L – H) (215)	12.09
(0 – G) (505)	2.7	(H – I) (280)	42.85	(M – G) (280)	2.14
(1 A – 2 A) (175)	45.7				



3.4. - Description of fire behavior.

As it was already indicated the behavior of the fire is the result of the environmental effects under the conditions of propagation. To describe the dynamic behavior of the fire, it is necessary to consider the information presented in the previous sections.

In the first place the conditions of the temperature and of the relative humidity, the first one over the 30ºC and the second with low values to 30%. These two variables exercise a drastic influence on the heating state and drying of the live and dead fuels. This circumstance makes the heating of the fuels by radiation and convection more effective resulting in ignition conditions being reached in a smaller time. According to this situation, the state of humidity of the fine and dead fuels, responsible for the ignition and propagation starting from the origin of the fire and existent in the area of occupation of the pattern of fuel model number 5, it reaches the values indicated in the following table. The content of moisture of the live fuels has been estimated at 185%.

Hour	**T (ºC)**	**HR (%)**	**Hcfm %(1h.) <5mm**	**10 h.% 5-25mm**	**100 h.% 25-75mm**
13:00	33.5	26	3.5	5.5	7.5
13:30	34	26	3.5	5.5	7.5
13:40	34	25	2	4	6
14:00	34	25	2	4	6

Fuel moisture dead of model 5

In second place the wind acts as a dynamic propeller changing the propagation conditions as a function of the intensity. It provides directional stability and consolidates the propagation in a preferential direction of advances. Strong intensities of the wind are manifested with quick propagations and frequent changes in the direction of the wind. These can result in erratic fire behavior at the fire front. During the period of time understood between the 13:00 and 14:00 hours the average wind speed is 4 km/h, with few oscillations around to this value. The direction stays with origin of southeast, with the following averages values, for the period understood between the 13:00 and the 13:35, 137,5º and for the period understood among the 13:35 and the 14:00, 140,3º.

With the last conditions, the development of the behavior of the fire during the first hour and from their beginning is considered by the following phases:

Phase I. Period of time: 13:00 to 13:35 h.:

The fire begins in the fuel model 5 and according to its description, this is presented with scarce quantity of combustible fuels, with dispersed and heterogeneous shrub with a hieght of 60 cm and with horizontal discontinuities. These conditions, the moderate slope of the land, and the low intensity of the wind speed, result in the relatively slow fire propagation during the 35 minutes of the period.

The propagation for the back of the fire is practically null and very low in the flanks, only showing with more activity in the head and areas from the contiguous flanks to the head. The maximum conditions for this period of time are the following ones: propagation speed: 2 m/min, fire line intensity of the front: 83 kw/m and length flame: 0,6m. with the purpose of knowing the propagation characteristics in the whole perimeter I included in the following chart the information around fire.

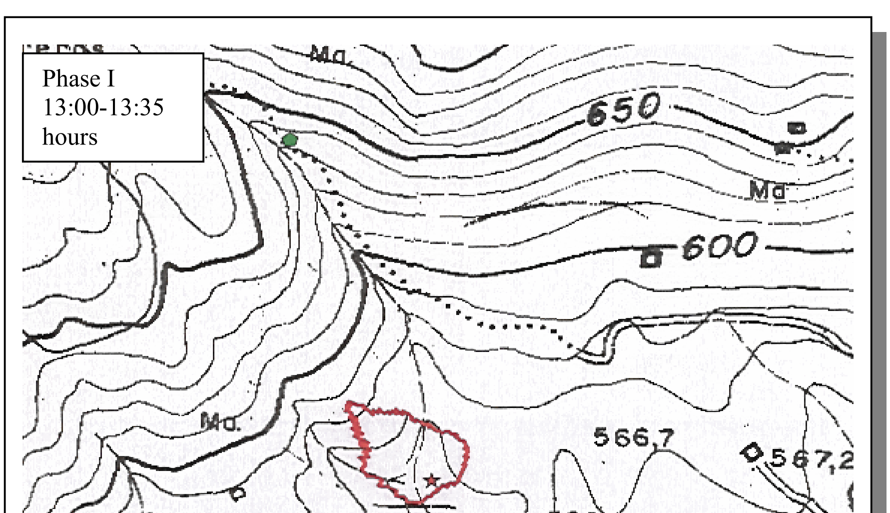
Degrees	Wind speed (Km/h)	Rate of Spread (m/min)	I (Kw/m)	Length of flame (m.)	Heat by unit of área (Kj/m^2)
0	6	2	83	0.6	3223
30	2.9	1	33	0.4	3223
60	1.4	0.8	16	0.3	3223
90	0.8	0.5	10	0.2	3223
120	0.4	0.3	8	0.2	3223
150	0.3	0.25	7	0.2	3223
180	0.3	0.2	7	0.2	3223
210	0.3	0.25	7	0.2	3223
240	0.4	0.3	8	0.2	3223
270	0.8	0.5	10	0.2	3223
300	1.4	0.8	16	0.3	3223
330	2.9	1	33	0.4	3223

Note: The 0º, is the head of fire propagation

From 13:00 o'clock at 13:35 hours, the direction of propagation of the head is in the interval 280º - 320º. It presents low growth for the back (0,2 m/min) and it liberates a reduced energy for meter (7 kw/m); outside of this interval fire development is low. In accordance with these conditions the developments of the forest fire is shown in the following chart

Direction (degrees)	Lenght (m.)
0 (Máximum slope)	70
30	35
60	28
90	17.5
120	10.5
150	8.75
180	7
210	8.75
240	10.5
270	17.5
300	28
330	35

These conditions conclude the first phase: the head of the fire is in the transition area among the areas of occupation of the models 5 and resulting Mr (fuel model of the composition of the fuel model type 4 and 7).



Phase II. Period of time: 13:35h. to 13:47 h.:

Starting from the 13:35 hours the penetration of the head of the fire takes place in the model Mr, for this situation the speed of the wind continues being of 4 km/h, The situation of the moisture of the dead fine fuels has changed in relation to the one considered for the fuel model 5. The change is due to the warm-up of the fuels receiving the energy liberated from the advance front. The considered effect is that of reduction of the moisture content by one percentage point for each one of the types of sizes. For the moisture of the live fuels has been considered 165%. With these conditions and a considerable change of slope in the new line of propagation (45,7%) and the complexity of the fuel model Mr, with high load of fuels (2,4 kg/m2), continuity so much horizontal as vertical of the fuels and presence of tree mixed with different shrubs under the crown, the propagation begins. The dynamic and energetic characteristics obtained present a great difference with the first phase. The maximum speed of propagation of the head or main front advance is 13,8 m/min., the fire line intensity is 7.577 kw/m and the length of flame, 5 meters. With the purpose of knowing the propagation characteristics in the whole perimeter I have included this information in the following chart

Degrees	Rate of spread (m/min)			Fire lin intensity (Kw/m)			Length of flame(m.)		
	M7	M4	MR	M7	M4	MR	M7	M4	MR
0	7	15	13.8	743	8783	7577	1.6	5	4.49
30	4	8	7.4	406	4749	4097.55	1.2	3.9	3.495
60	2	4	3.7	181	2106	1817.25	0.8	2.6	2.33
90	2	2	2	103	1196	1032.05	0.7	2	1.805
120	1	1	1	64	835	719.35	0.5	1.7	1.52
150	0.7	1	0.955	53	684	589.35	0.5	1.6	1.435
180	0.5	1	0.925	50	642	553.2	0.5	1.5	1.35
210	0.7	1	0.955	53	684	589.35	0.5	1.6	1.435
240	1	1	1	64	835	719.35	0.5	1.7	1.52
270	2	2	2	103	1196	1032.05	0.7	2	1.805
300	2	4	3.7	181	2106	1817.25	0.8	2.6	2.33
330	4	8	7.4	406	4749	4097.55	1.2	3.9	3.495

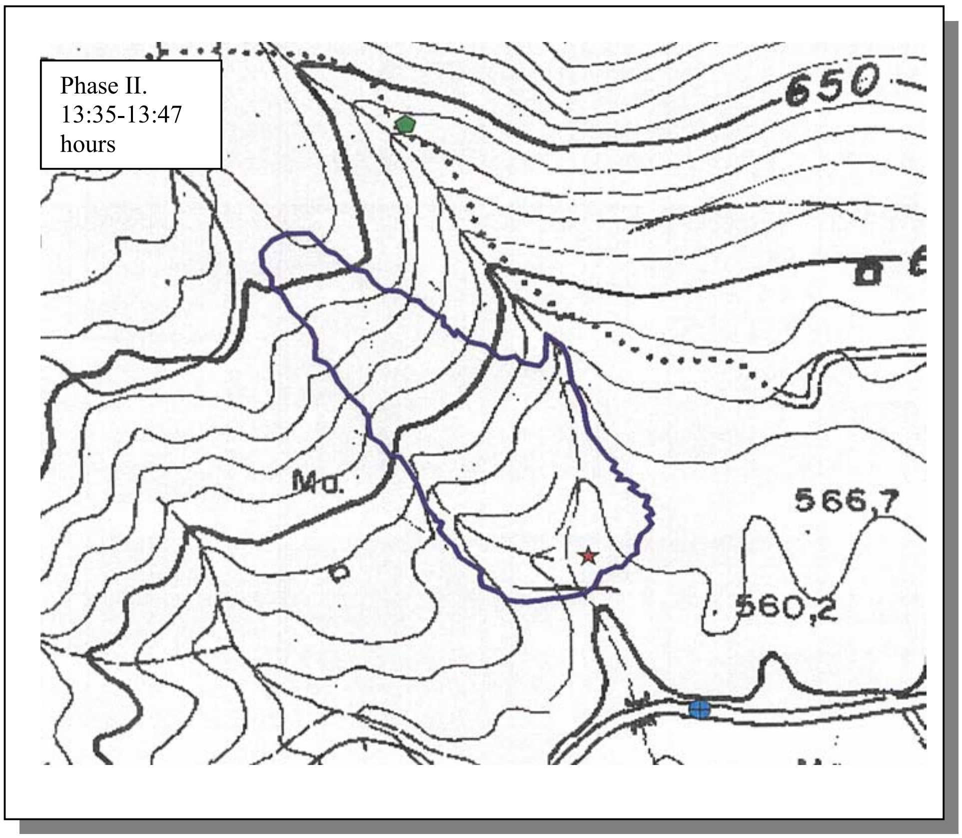
Fire spread characteristics in function of maximum slope for diferent point

The energy development from the fire provided the best conditions for transition from surface to crown of tree, the combustion evolves in two levels, a first level in surface and a second level through the tree canopy, both combustions are directly dependent.

To determine such an evolution it has been necessary to evaluate the critical intensity (Van Wagner 1977) for the formation of crown fires, this depends on the average height between the surface and the first group of branches of the tree, and the moisture content of the leaves located in this branches. The value obtained for the critical intensity is of 363.84 kw/m.

whenever the critical intensity stays below the fire line intensity of the advance front, the conditions are given for the transition and simultaneous propagation by crown and surface.

This circumstance stays along the propagation for the fuel model (Mr).The consequence of this propagation is the high consumption of the fuel in canopy of the trees. The great quantity of evaporated water coming from the vegetation, as well as the remaining volatile components liberated by effect of the combustion incorporate to the convection column that for effect of the quantity of produced ascendant thermal energy, in the vertical of the fire manifesting a great domain of the power of the fire. The atmospheric instability located at surface level, facilitates the elevation of the plume of the column. With these conditions after twelve minutes of propagation completes phase II. Tthe surface spread from the origin of the fire is indicated in the map below:



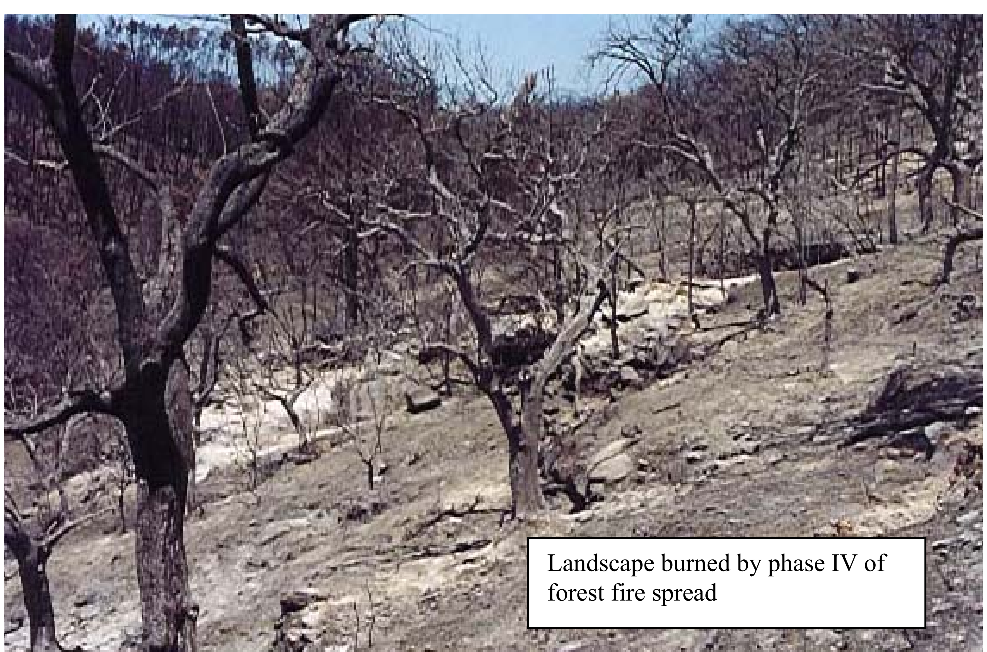
Phase III. Period of time: 13:47 to 13:57 h.:

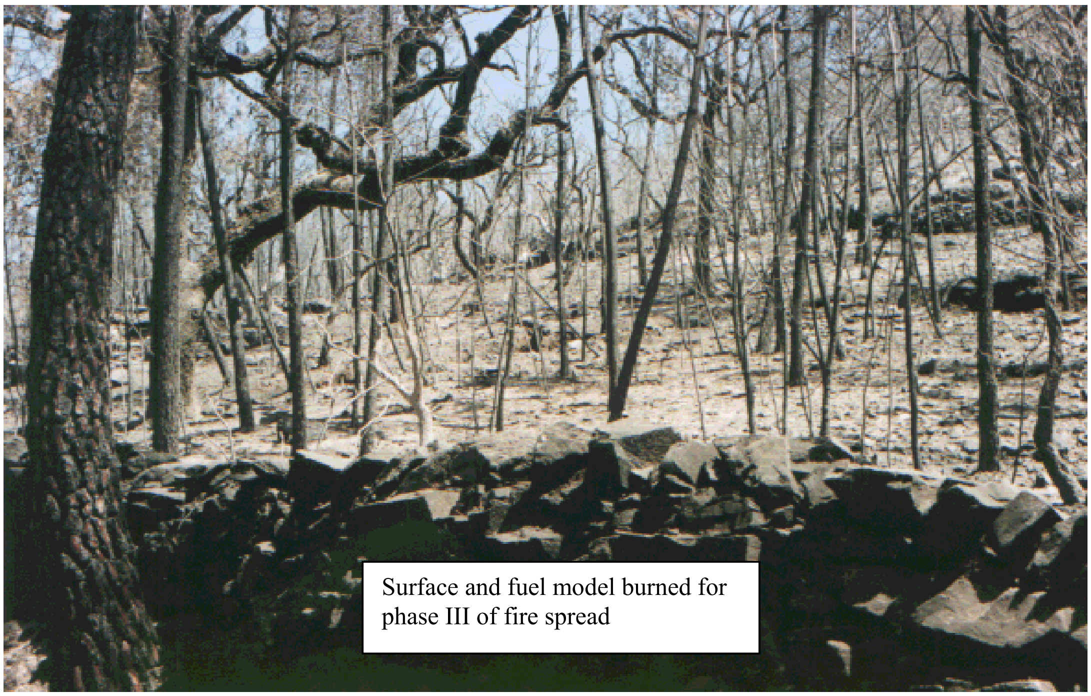
The conflagration responsible for the explosive spread occurred in the first part of this phase. The collapse of the thermal inversion indicated in the description of the present analysis, and the fragility of thermal inversion because it did not have a solid bond with the hillsides for the instability effect. The local nucleus of low pressures, a reorganization of the layers of air above the fire, resulted in rapid flow of fresh air and oxygen to the combustion, facilitating a sudden and quick propagation of the fire. The great quantity of vapor of water located in the convection column in contact with the high mass of hot air from the center of the combustion mixingwith masses of air to upper heights resulted in cooling of the mass of air.

The direct effect of this phenomenon is the formation of masses of cold air or masses of air to smaller temperature and consequently of more weight. This situation causes the formation of turbulences and descending currents in a jet with very high speed against the floor from the convection column. In such a way that when they arrive at the fire, the currents of divergence dynamically impel the heads, the flank and the back of fire at a high level with highly dynamic and explosive propagations and great fuel consumption.

I ATTACHED PHOTOGRAPHIC

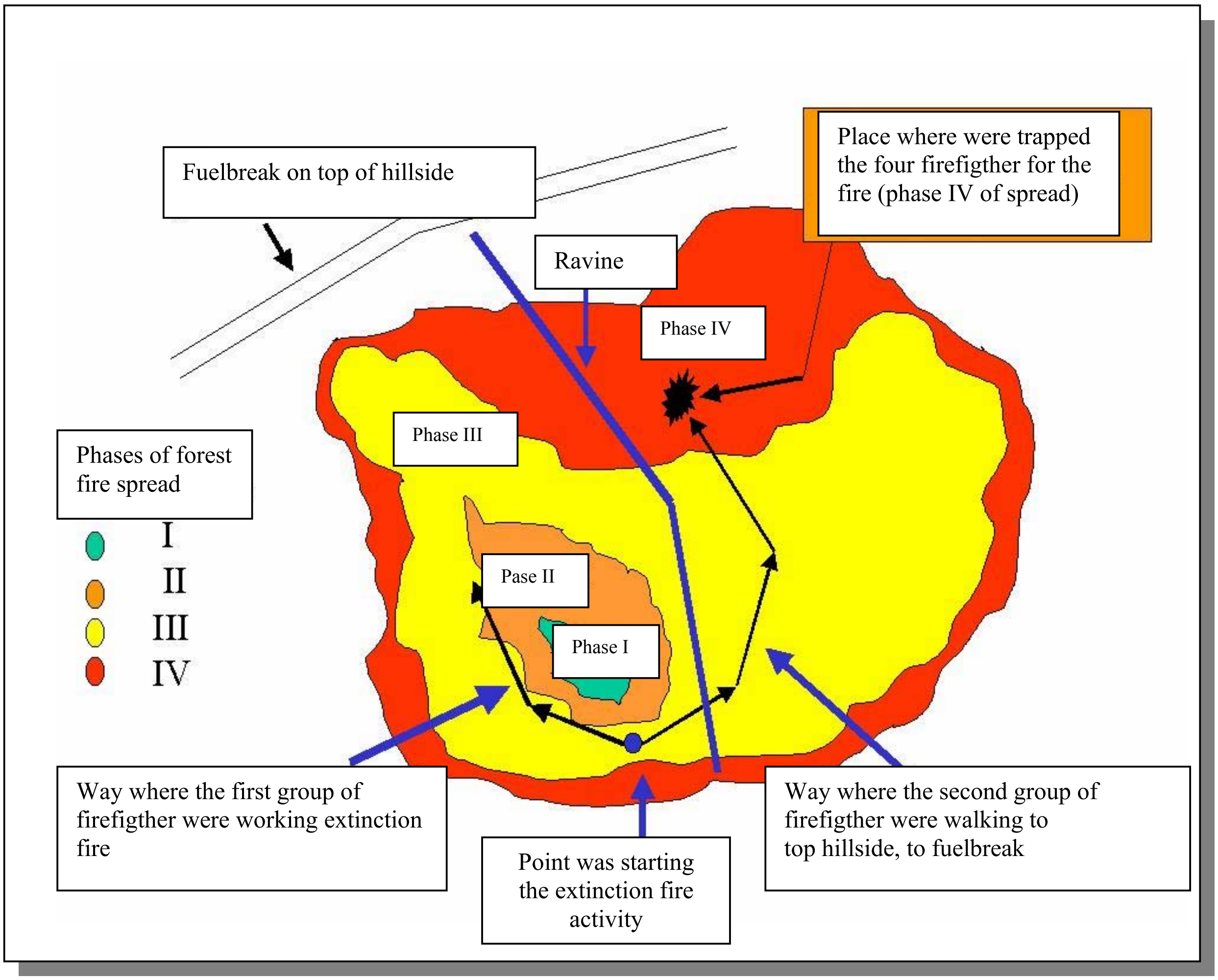

Point was starting the fire


Landscape burned by phase IV of
forest fire spread



Surface and fuel model burned for phase III of fire spread

Way where the four firefigther went to upslope for to search a safety place



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