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# Criteria for determining the current activity of torrents in their depositional areas

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**Abstract** Alluvial fans formed by the perpetual transport and deposition of material by torrential streams, frequently exhibit trenches on their main body. According to some scientists these trenches represent recent torrent activity in the deposition area. The deposits within these trenches can be classified into several categories depending on their residence time. The classification is based on criteria relating to their general appearance and the vegetation cover. It was shown that when a specific width of the trench is occupied by deposits which according to the previous classification are very recent, the torrent should be viewed as active. Where the occupied trench width exceeds a certain limit, the torrent is in a high risk active condition.

## INTRODUCTION

The main depositional area of torrential streams is located below the gorge section. The continuous depositional activity of the torrent in this area produces an alluvial fan. If we observe the main body of such features in the field we will see that they are traversed by one or more trenches. According to Bull (1962, 1964) and Wasson (1977) these trenches are formed by the flood waters of the torrent stream after the main body of the fan has been formed. Their width and depth varies considerably. Bull (1962) reports depths from 1 to 15 m and widths from several metres up to several tens of metres. Within the depositional zone, the entire torrent activity is concentrated within the trenches. By the term activity we mean any process which contributes to the formation or destruction of the main body of the landform. The total width which the trenches occupy on the surface of the depositional landform can be considered to represent the zone of recent activity (z.r.a.).

Wasson (1977), considers that if deposition prevails within these trenches, the depositional landform is considered to be active, because its structure is being "supplemented" by new transported material (fan entrenchment-active situation). If erosion phenomena are observed within the trenches and the previously deposited material is being removed, the landform is considered to be in an inactive state which leads to its destruction (fan incision-inactive situation). A sample of torrents and their respective deposition landforms was used to investigate further the suggestions of Wasson (1977).

The following aspects were considered:

(a) the form of the deposits and the fraction of the total width of the trenches (i.e. z.r.a.) occupied by the deposits in the case of active fans;

(b) the form of the deposits and their width in the case of inactive fans.

## FIELD INVESTIGATIONS

As noted above, Wasson (1977) considers that the depositional landform should be viewed as active when there is material accumulating within the trenches. However, the presence of debris within the trenches is not in itself sufficient evidence of recent[1] transport. This is because the material may have been there for several decades, in the absence of significant floods capable of remobilizing and transporting the debris. It is therefore useful in the first instance to determine whether the material accumulated within the trenches was deposited recently or whether it is a product of older torrent activity. This has led us to attempt a general classification of the debris found within the trenches and forming the main body of the fan, based on the date of its transport and deposition.

The classification is based on two external morphological features which are easy to identify in the field. The first is the vegetation growing on the surface of the deposits and the second is their surface appearance. This approach was used to investigate 29 alluvial fans scattered throughout the

**Table 1** The sample torrent streams and their basin area.

| No. | Torrent stream | Drainage area (km$^2$) | No. | Torrent stream | Drainage area (km$^2$) |
|---|---|---|---|---|---|
| 1 | Vatonias | 236.46 | 16 | Moustheni | 12.40 |
| 2 | Vogeni | 2.30 | 17 | Nea Apollonia | 232.90 |
| 3 | Volinaios | 27.00 | 18 | Douvias | 8.00 |
| 4 | Vyrhon | 23.10 | 19 | Xerias | 15.30 |
| 5 | Zagliveri | 126.80 | 20 | Paleovraha | 8.50 |
| 6 | Thermi | 52.80 | 21 | Platanias | 8.50 |
| 7 | Thermopyles | 8.80 | 22 | Poroi | 96.00 |
| 8 | Kamenikia | 32.50 | 23 | Portaikos | 137.55 |
| 9 | Karpenisi | 3.00 | 24 | Skalas | 33.70 |
| 10 | Kerinitis | 80.00 | 25 | Ipati | 28.40 |
| 11 | Kouvelorrema | 12.42 | 26 | Phoinikas | 27.00 |
| 12 | Marathias | 33.00 | 27 | Halandritsa | 11.70 |
| 13 | Meganitis | 60.08 | 28 | Haradros | 19.50 |
| 14 | Megas | 4.70 | 29 | Hourou | 7.70 |
| 15 | Messoropi | 15.40 | | | |

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[1] The term "recent" is used not in its classic meaning but with the meaning attributed by some researchers (recent (Wasson), Jung (Aulitzky)) in order to characterize torrent activity which is recent in relation to the longer-term activity of a torrent.

**Table 2** A deposit classification based on external morphological features.

| Deposit category | Vegetation description | Surface appearance |
|---|---|---|
| Category A | No trace of vegetation found | Moveable pebbles without morphologic, chromatic, mechanical, or chemical alteration |
| Category B | Very slight traces of vegetation in the form of weak forbs | Superficial pebbles linked together by matrix material (e.g. loam). Less moveable |
| Category C | Some forb vegetation. Rarely small trees or shrubs | Pebbles with advanced chromatic and morphologic alteration; more or less joined together |
| Category D | Shrubby or woody vegetation, depending on the plant association. Occasionally cultivated | Surface covered by a soil layer. Only a few pebbles visible on the surface |
| Category E | Shrubby or woody vegetation sometimes with a coverage of 100%; or systematically cultivated fields | Except for a few gravel particles no pebbles appear on the surface. Difficult to distinguish from soils of non alluvial origin. |

Greek mainland and having basin areas ranging between 2.5 and 230 km$^2$ (see Table 1). The deposits which make up the main body of the depositional landform and those which fill the trenches can be subdivided into five categories according to their residence time at the location where they were last deposited (see Table 2 and Figs 1-4).

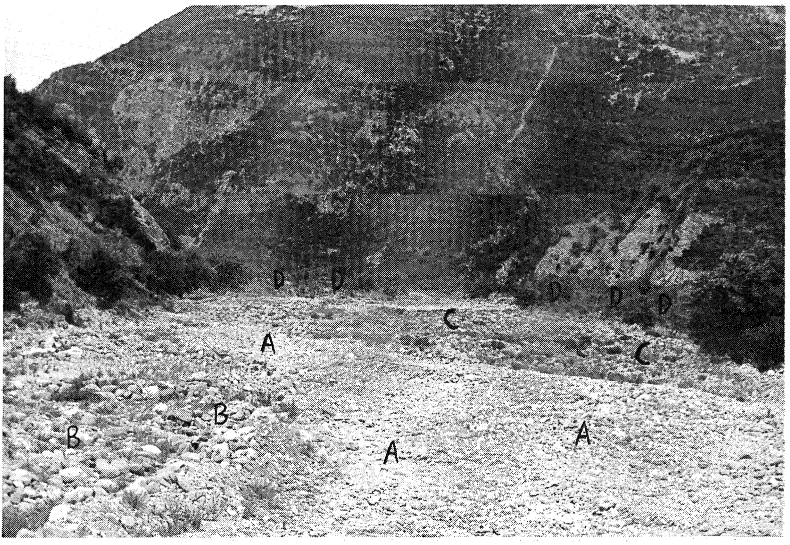

**Fig. 1** Deposit categories *A*, *B*, *C*, *D* occurring on the same depositional landform.

## The width of the deposition zone

Our research also confirmed that the width of the deposition zone of category A deposits inside the trenches corresponds to the width occupied by the annual flood associated with the respective torrent. This conclusion was based on the

**Fig. 2** Details of category *A* deposits; no vegetation exists.

following evidence.

In every alluvial fan included in the sample, a randomly selected cross section $E_1E_2E_3$ was defined. Within this cross section the width occupied by category *A* deposits and the height of the respective alluvial terraces up to the point where category *B* deposits appear were measured (Fig. 5).

Thus, we calculated the area $F$ of the cross section $K_1K_2K_3K_4$ and using the formula $R = F/P$, we calculated its hydraulic radius ($R$). The axial slope ($J$) of the cross section was also measured. By using these values in the Manning-Strickler formula we estimated the peak flow velocity $U_{\max}$ at this point, i.e.

$$U_{\max} - KR^{2/3}J^{1/2} \tag{1}$$

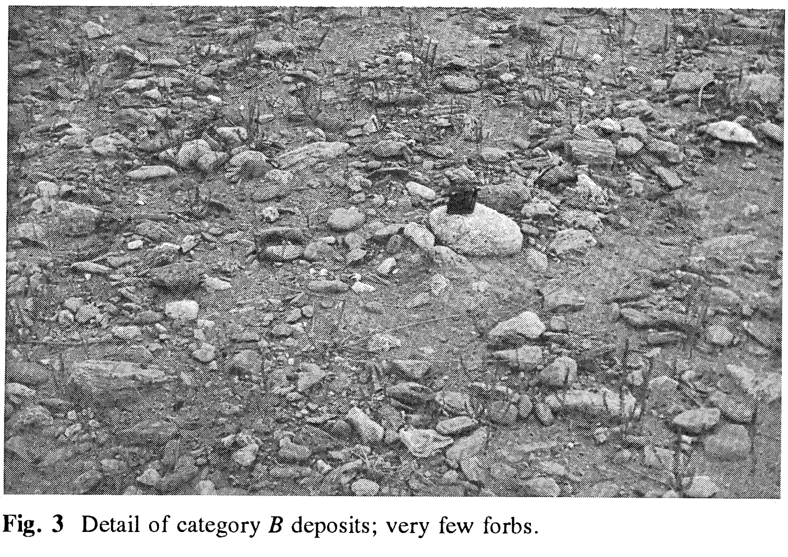

**Fig. 3** Detail of category *B* deposits; very few forbs.

**Fig. 4** Detail of category *C* deposits; adequate vegetation, pebbles are linked together.

where:

$K =$ the roughness coefficient;

$R =$ the hydraulic radius defined as $R = F/P$ where $F$ is the cross-sectional area and $P$ the wetted perimeter;

$J =$ the axial slope of the channel measured locally.

The magnitude of the annual flood associated with each study torrent was estimated using the formula of Fuller as given by Kotoulas (1979) which estimates the maximum flood for a specific frequency in years i.e.

$$Q_{\max} = Q_1(1 + b_{\log 10}T)\left[1 + \frac{2.66}{F^{0.30}}\right] \tag{2}$$

where $Q_1$ = the mean flood discharge with a frequency of one year ($m^3\ s^{-1}$). This is calculated as:

$$Q_1 = 1.80\, F^{0.8}$$

where $F$ = the area of basin ($km^2$); and $T$ = frequency or return period, calculated as follows:

| Frequency (years) | | 1 | 5 | 10 | 20 | 50 | 100 |
|---|---|---|---|---|---|---|---|
| Parameter | $1 + b_{\log 10}T$ | 1.000 | 1.559 | 1.800 | 2.40 | 2.359 | 2.600 |

Thus, in this case the formula takes the form:

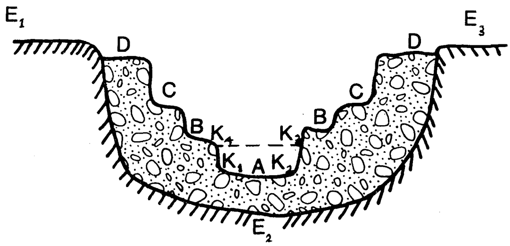

**Fig. 5** A typical cross section of an alluvial fan trench.

$$Q_{1\max} = Q_1 \left[ 1 + \frac{2.66}{70.30} \right] \mathrm{m}^3\ \mathrm{s}^{-1}$$

After the flood discharge were estimated a check was undertaken to determine the size of cross section needed to contain the annual flood discharge.[2] This check indicates that for 27 out of the 29 alluvial fans included in the sample, the required capacity was approximately equal to the area of the cross section $K_1K_2K_3K_4$ (Fig. 5). Table 3 lists the areas of the cross sections as measured in the field, and the capacities required to contain the annual flood.

Table 3 confirms the validity of the above conclusions. In addition, since the flow depth associated with the annual flood does not differ significantly from the height $K_1K_4$ measured in the field, the width of the flood cross section can be taken as equal to the width $K_1K_2$. In other words, the bed width occupied by the annual flood is covered by category *A* deposits. This is also the reason why for category *A* deposits there is a complete absence of vegetation. The annual disturbance by the flood prevents the growth of vegetation. Category *A* deposits thus have a residence time ranging from a few days up to several months.

## The structure of the deposits

Category *A* deposits are sometimes well stratified with a smooth surface and sometimes unstratified with an irregular wave-like surface. These two types of deposit may be found at different positions within the same trench. This phenomenon is obviously related to the shear stress of the water which in turn depends on the bed slope. Wave-like surfaces were observed in reaches with increased slopes, whereas the surfaces were smoother where axial slopes were less and widths greater. Field observations of the beds of the trenches have

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[2] The check was undertaken in the following way: by using the continuity equation $Q = F.u$ and substituting $Q_{1\max}$ for $Q$ and $U_{\max}$ for $u$ the required cross section capacity can be calculated by the Manning-Strickler formula. Solving for $F$ provides the cross section area. This area is compared with the area measured in the field cross sections $K_1K_2K_3K_4$.

**Table 3** Measured trench cross section areas and required capacities for the annual flood.

| No. | Torrent stream | Measured trench area ($m^2$) | Required trench capacity ($m^2$) | No. | Torrent stream | Measured trench area ($m^2$) | Required trench capacity ($m^2$) |
|---|---|---|---|---|---|---|---|
| 1 | Vatonias | 141.40 | 143.6 | 16 | Moustheni | 7.40 | 6.71 |
| 2 | Vogeni | 2.45 | 2.15 | 17 | Nea Apollonia | 155.50 | 173.44 |
| 3 | Volinaios | 13.40 | 14.21 | 18 | Douvias | 7.00 | 5.10 |
| 4 | Vryhon | 14.80 | 12.86 | 19 | Xerias | 8.50 | 8.24 |
| 5 | Zagliveri | 110.80 | 116.96 | 20 | Paleovraha | 4.60 | 4.41 |
| 6 | Thermi | 32.10 | 55.27 | 21 | Platanias | 5.10 | 5.95 |
| 7 | Thermopyles | 6.90 | 5.80 | 22 | Poroi | 43.20 | 48.25 |
| 8 | Kamenikia | 35.8 | 31.25 | 23 | Portaikos | 49.40 | 52.84 |
| 9 | Karpenisi | 2.40 | 2.21 | 24 | Skalas | 18.60 | 15.57 |
| 10 | Kerinitis | 39.40 | 33.06 | 25 | Ipati | 13.75 | 10.74 |
| 11 | Kouvelorrema | 14.10 | 8.172 | 26 | Phoinikas | 37.50 | 38.92 |
| 12 | Marathias | 15.60 | 13.89 | 27 | Halandritsa | 7.10 | 7.89 |
| 13 | Meganitis | 38.40 | 32.45 | 28 | Haradros | 14.00 | 10.38 |
| 14 | Megas | 2.90 | 2.71 | 29 | Hourou | 2.60 | 2.70 |
| 15 | Messoropi | 4.95 | 6.97 | | | | |

shown that for all the alluvial fans included in the sample, wave-like surfaces occurred where the axial inclination exceeded 3% and smooth surfaces occurred where the inclination was less than 3%.

**Residence times of the deposits** The deposits of categories *B, C, D* and *E* upon which various plant species grow must clearly remain undisturbed for substantial periods of time. More specifically, the field observations demonstrated that the longer their residence time at a particular position the more advanced is the colonisation by pioneer species, initially, and woody species subsequently. In the case of categories *B, C, D* and *E* deposits, it is not possible to estimate the exact residence time, as in the case of category *A* deposits. However, we may safely say that category *B* deposits have residence times in excess of 5-10 years.

In conclusion, it is considered useful to emphasise the following points, in relation to the findings outlined above:

(a) In fully-developed alluvial fans we normally encountered deposits in all five categories. Usually, they are distributed as follows. Category *A*, *B* and *C* deposits are found inside the trenches. In rare cases it is also possible to find category *D* deposits in such locations. On the contrary, the deposits found outside the trenches (which also constitute the main body of the fan) are principally of categories *D* and *E*.

(b) The boundaries between the five categories are not always clearly defined in nature.

(c) Very often, although there is a suitable soil layer (category *D* or *E* deposits) woody species may not be present, and only evergreen broadleaved shrubs are found due to the local vegetation associations. In very dry-warm climates even evergreen broadleaved shrubs may have a limited presence.

(d) Sometimes, when flood waters overflow onto areas with category *D* and *E* deposits, they may leave pockets of category *A* deposits overlying category *D* and *E* deposits. In this case, care is required in applying the classification, because macroscopically the deposits may be classified as *D* and *E* whereas at a more detailed level they may be classified as *A*.

(e) All the above soil-vegetation relationships were developed in Greece. It is believed that the same relationships will apply in other countries with a similar climate. Additional research may be necessary to extend the approach to other regions.

## RESULTS

Using the findings outlined above and by undertaking detailed investigations of the depositional landforms included in the sample of alluvial fans, we concluded that only deposits in the first two categories of the classification can be considered to provide evidence of a dynamic condition. Deposits in the next category show features and characteristics which indicate that the materials are not moving.

We have previously classified the depositional landforms in the sample as being active or inactive based on the conclusions of Wasson (1977) (see Table 4). Table 4 also presents the proportions of length and width of the trenches occupied by category *A* and *B* deposits. By comparing the two sets of information we find that all the depositional landforms which are in an active condition according to Wasson (1977) have category *A* and *B* deposits occupying over 30% of the width of the z.r.a. and its entire length. The remaining examples are all inactive.

Furthermore, based on field observations throughout Greece and on the reports of the Forest Offices and local authorities etc., we found that many alluvial fans had category *A* and *B* deposits covering 80% of the width of the z.r.a. These were characterized by frequent flood events and severe disasters during the last decade.

Thus, we come to the general conclusion that in cases where category *A* and *B* deposits occupy at least 33% of the average width of the zone of recent activity (z.r.a.) along its entire length, the zone is functioning at the present time and the alluvial fan is in an active condition. Conversely, where the z.r.a. is not functioning at present the alluvial fan is inactive. More specifically, those fans where category *A* and *B* deposits cover more than 80% of the width of the z.r.a. should not only be considered as being in an active condition but also in a dangerously active condition.

**Table 4** Percentages of the total width and length of the z.r.a. occupied by Category *A* and *B* deposits compared to the activity classification based on Wasson (1977).

| No. | Torrent stream | Total percentage of z.r.a. width and length. Deposits *A* and *B*: | | Condition of depositional landform[a] | No. | Torrent stream | Total percentage of z.r.a. width and length. Deposits *A* and *B*: | | Condition of depositional landform[a] |
|---|---|---|---|---|---|---|---|---|---|
| | | Width | Length | | | | Width | Length | |
| 1 | Vatonias | 40% | on entire length | active | 16 | Moustheni | 10% | per locations only | inactive |
| 2 | Vogeni | 95% | on entire length | active | 17 | Nea Apollonia | 90% | on entire length | active |
| 3 | Volinaios | 60% | on entire length | active | 18 | Douvias | 70% | on entire length | active |
| 4 | Vryhon | 55% | on entire length | active | 19 | Xerias | 80% | on entire length | active |
| 5 | Zagliveri | 30% | on entire length | active | 20 | Paleovraha | 20% | per locations only | inactive |
| 6 | Thermi | 20% | per locations only | inactive | 21 | Platanias | 90% | on entire length | active |
| 7 | Thermopyles | 10% | per locations only | inactive | 22 | Poroi | 70% | on entire length | active |
| 8 | Kamenikia | 30% | on entire length | active | 23 | Portaikos | 80% | on entire length | active |
| 9 | Karpenisi | 80% | on entire length | active | 24 | Skalas | 80% | on entire length | active |
| 10 | Kerinitis | 75% | on entire length | active | 25 | Ipati | 70% | on entire length | active |
| 11 | Kouvelorrema | 80% | on entire length | active | 26 | Phoinikas | 80% | on entire length | active |
| 12 | Marathias | 90% | on entire length | active | 27 | Halandritsa | 70% | on entire length | active |
| 13 | Meganitis | 95% | on entire length | active | 28 | Haradros | 90% | on entire length | active |
| 14 | Megas | 80% | on entire length | active | 29 | Hourou | 80% | on entire length | active |
| 15 | Messoropi | 10% | per locations only | inactive | | | | | |

[a]Based on Wasson (1977).

## CONCLUSIONS

On the basis of the above work it is possible to classify the deposits of an alluvial fan into categories of various ages based on their major morphological features. From the viewpoint of risk and protection what interests the torrent manager is the presence and mobility of the more recent deposits within the trenches of alluvial fans, since their remobilization can cause further damage. We believe that simply by studying the nature and distribution of the recent deposits it is possible to determine whether a trench is active and the degree of risk associated with this activity. For this reason, it is hoped that the results presented in this paper may be of more general interest.

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