SEVERAL FLOW EVENTS ON THE MARGIN OF THE ALGERIAN-MOROCCAN SAHARA AND THEIR MORPHOLOGICAL CONSEQUENCES

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Forward

The paper by Fernand Joly (1953) it is one of four classic eyewitness accounts of sheetflooding — the important but poorly understood process (Vincent et al., in prep.) first discussed by McGee (1897). Joly's paper was published in the proceedings of the 1952 meeting of the International Geological Congress in Algiers. Thus, it is difficult to obtain and is written in French, so authors inevitably cite a summary of the work in Chow (1964, section 24, pages 24-25; by R.O. Slatyer and J.A. Mabbutt). In other words, very few English speaking scientists have read the original 1953 paper.

Fortunately, the work is here translated by Julie Woodward, who is a native speaker of both French and English and is also a geomorphologist. Now English speaking scientist interested in the process of sheetflooding, and the origin of alluvial fans and pediments, can benefit from Joly's fascinating observations.

Kirk Vincent

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McGee, WJ, 1897, Sheetflood erosion: Geological Society of America Bulletin, v. 8, p. 87-112.

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Several flow events on the margin of the Algerian- Moroccan Sahara and their morphological consequences

Translation of Joly([1]) (1953) from French to English

by Julie Woodward

Summary

The author describes two types of diffuse flow in sheets (sheet-floods) and two types of concentrated flow (floods) which he witnessed on the margin of the Algerian-Moroccan Sahara.

He then explains several of the morphologic effects of these types of flow. Under the climatic conditions currently existing in this region, concentrated flow and diffuse flow exhibit several common characteristics: intermittence, inability to perform linear vertical erosion and active lateral erosion. The two types of flow work together to plane surfaces by removing successive layers of the topography, leading to the *pediplain* of L. C. King.

Joly, F., 1953, Quelques phénomènes d'écoulement sur la bordure du Sahara, dans les confins algéro-marocains, et leurs conséquences morphologiques, pp. 135-146, in Comptes Rendus XIX Congrés Geol. Intern., Algiers, 1952, pt.VII, Déserts Actuels et Anciens, 1953.

Recently attention has been drawn, in the northwestern Sahara, to particular types of flow and erosion long recognized in the deserts of the American west and, more recently, in those of southern Africa ([2]). I would like to present several observations made in southern Morocco and western Algeria and show how these fit into the model for evolution of topography at a desert margin.

Types of Diffuse Flow

Diffuse flow occurs when water flows without succeeding in concentrating itself into channels which serve as gutters. It is to this type of flow that American authors gave the name "sheet-flood" or "sheet-wash". Since the phenomenon is linked to specific topographic and meteorological conditions, it is necessarily discontinuous and, as a result, viewed only by chance. It has, therefore, rarely been described. Having traveled frequently along the northwestern margin of the Sahara during the rainy season, I have had the opportunity to witness several of these sheet flows which, without reaching the magnitude of the one described by McGee, are indisputably of the same type.

1) **Hillslope sheet-flood** — One of the most remarkable occurred on January 22, 1950, in late morning. I was returning from a tour of the lower Dra with my colleague J. B. Panouse. We were heading towards Aouïnet Torkoz by way of the alluvial slopes on the south flank of Jebel Amsmerdane (1:200,000, Taïdalt, 22-167), which slope towards the "feija" of Ida ou Mellil. These alluvial slopes, dissected by the oued (*) which come from the Bani, are formed of large coalescing flat cones, sometimes depositional and sometimes

* Note from the translator: "Oued" is the Arabic term equivalent to arroyos or washes of the southwestern U.S.

erosional, which are encrusted at their apex. The crust itself is covered by more recent deposits: pebbles derived from disturbance of the crust itself and fine-sand sized debris. The vegetation is far from being non-existent but is very discontinuous. The weather had been bad since the evening of the 20th, a succession of storm systems linked to a low pressure system crossing Morocco having caused several violent rainstorms. The sun was veiled; the incursion of polar maritime air had lowered the temperature considerably and the air was very humid. In addition, in spite of the gusts of wind blowing from the west and southwest, evaporation was very low.

On the morning of the 22nd, the ground everywhere was soaked and we had a hard time catching our camels on the slippery mud of the "mader" where they had wandered. All morning, cloudbursts had hindered breaking camp; and the weather once again grew worse about 11:30 AM. From 11:50 to 12:30, we were hit by a first downpour along a ravine with very steep sides. Nothing particular happened to the banks but puddles formed in the bed of the oued which began to flow. Soon thereafter, about 12:45, a second shower, even more violent than the first, surprised us on the fan of Ida ou Mellil. It was this rain shower, which fell furiously and without interruption until approximately 1:20, with two or three particularly violent periods, which started a true "sheet-flood" on the slope.

From the beginning, the fine grained areas between the scattered cobbles absorbed water until they were saturated and puddles appeared which soon became linked to one another by a complex network of independent and constantly changing rivulets. Old channels, several centimeters above the main grade, began to fill but soon over-topped their washed out banks, but no new drainage channels formed and no hierarchy established itself between the water courses. Because the rain did not cease,

the water level rose in all the puddles which coalesced, erasing the fine network formed by the first runoff. We were now wading in a unified sheet of water 2-3 cm deep, which submerged our sandals and propagated quickly downslope. At this point, the flow was neither clear nor muddy but carried fine sand sized particles. The flow showed no competence to carry gravel greater than or equal to 1 cm, but one could occasionally see pebbles of this size tumble on a sharp edge and change position as the fine sediment which surrounded them was washed away. Once again, during this stage no channels formed; however, sand did sometimes accumulate in the lee of small obstacles, either as elongate dikes or as micro-deltas. This stage lasted approximately 10 minutes. At last the flow began to abate. The flow became concentrated in very wide, shallow ravines towards which converged the small channels draining the puddles created by the break up of the sheet flow. Micro-rills formed everywhere as the water level dropped in the main channels. Everything stopped very suddenly and the saturated ground began to dry.

2) Alluvial plain sheet-floods — The talus slopes and alluvial fans are not the only places where sheet flow is observed. It is also observed on the alluvial plain: on the silty valley floors or the edge of playas (floor of closed depressions).

I saw one very short example, on February 14, 1949, in the portion of the Daoura enclosed by the Kem-Kem. Between the limestone walls, the valley is entirely filled by a silty deposit, cracked by drought and criss-crossed by flood channels. As a result of the rainfall, the clayey silt quickly became wet and swelled. The cracks disappeared and the entire surface became impermeable. This wet layer was in fact quite thin since footsteps sinking through the mud reached dry ground; however, it was thick enough to

support flow. Surface rivulets ran towards the channels following slight surface irregularities, but without downcutting. Those which went down the slope built flat cones upon which they dispersed. As the storm continued, the rivulets overflowed and merged into one large sheet which emptied in a surge into the deeper channels, rounding their angular banks. In contrast, as flow slowed, the sheet of water became concentrated into a few channels which downcut quickly into the alluvial surface.

Types of Concentrated Flow

On the margin of the northern Sahara, concentrated flow occurs only during the flood season. During the majority of the year the oued are dry and no distinction is made between flow and flood; in the language of the region, the word for flood is also *"oued"*. The phenomenon has been observed and described often enough that I won't dwell on it: I will nevertheless describe two examples.

One can recognize two kinds of floods:

1) **The local floods** are caused by rains which affect only a restricted area. Like *sheet-floods*, we see these types develop after large storms and on ground which was already wet. Like the sheet-floods, they affect only a limited portion of the basin and act independent of the events taking place in the neighboring area.

Following is an account of this sort of flood, observed to the south of Taouz on the oued Amuri, during the night of the 1st to 2nd of December 1949. The rain had started on the morning of the 1st as a persistent drizzle, wetting the soils and bed of the oued, but without succeeding in generating any runoff. The rain had stopped during the afternoon, but large low clouds scuttled across the sky, pushed by a west wind. The rain resumed more

violently that night, as heavy downpours, between 7 PM and midnight. All of the washes began to flow and sheets of flow covered the fans. In the bed of the oued, puddles appeared about 9 PM, due to both rain water and the emergence of ground water flow. These puddles, as they grew, coalesced into long *guelta* (ponds) agitated by a slight current. Towards midnight, at the same time that the lateral sheet flooding ceased, a wall of water 1 m to 1.5 m high, fed by the gullies from the slopes and the channels draining the alluvial fan and traveling at a speed of 1 to 2 meters per second, appeared in the 15 m wide channel. The flood waters began to drop almost immediately after this, in spite of the rain which had returned as a light drizzle, although the reduction in flow didn't become noticeable until 6:00 in the morning. Between 7:30 and 8:15 AM the water level dropped abruptly by 60 cm and the gravel bars separating the channels reappeared. When I left the area, about 10:00 AM, one could walk with dry feet. The thalweg had barely been changed: a few steep sections of river bank had crumbled, a little more sand here and a little less gravel there, were the only result of the flood.

2) Distant floods originate from precipitation fallen in the mountains, with a shorter or longer lag time before the arrival of the flood crest. They always affect an important percentage of the watershed, sometimes even the whole watershed. In the company of J. Dresch and R. Raynal, I saw some very beautiful examples in October 1950 ([3]).

On October 12 at 6:30 PM, a very large flood resulting from rain (approximately 100 mm) which fell from the 6th to the 8th of October on the High-Atlas watershed of the Guir on the Saoura, passed at Kerzaz. On the morning of the 13th, the water level was still rising. The oued, which was very wide and ran at the foot of the Grand Erg, was full of yellow water on which floated large muddy chunks. These bit into the banks, carrying away,

in one fell swoop, big pieces of dune or mud. On the same day, at 12:30, approximately 18 hours after passing Kerzaz, the flood crest reached the Foum Kheneg, 100 km downstream, filling the dried up channels, breaking up the dunes and cascading over the retaining wall protecting the road to Touat before dividing into two unequal branches: the larger heading towards the Sebkah Melha, the smaller towards oued Messaoud. At Beni Abbès, on the night of the 14th, the water level in the oued was falling but the oued was still too wide and turbulent to cross on foot. We could see the water leaping over the retaining wall, causing much aggradation upstream and, in contrast, creating huge holes downstream in which whirlpools formed which undermined the foundation of the retaining wall. On the lateral banks which had been submerged, we could still see traces of alluviation and in many places the limit reached by the water was marked by a little erosional cutbank formed in the mud. The water level continued to drop slowly all day on the 15th. That night, towards 5 PM, a large crack formed in the retaining wall. The water level dropped visibly and within several minutes the flow concentrated itself into four or five channels towards which flowed multiple rills which downcut into the main river bed. The flow remained thus concentrated for another couple of days, until the arrival of a new flood.

Several Morphological Consequences

1) Effects of Concentrated Flow — The work performed by the concentrated flow in the oued is the cleaning-out of the thalweg by the floods. Observation shows that the dominant effect of this work consists, on the one hand, of widening the bed of the channel by lateral erosion, and on the other hand of reworking the flow channels. Very particular conditions such as

vertical structures or constrictions, for example, are necessary for us to observe any appreciable evidence of vertical erosion.

From the beginning, the flood waters are heavily loaded because an abundance of loose material is found in the thalweg. It is the lower layers of the flood waters which first reach their carrying capacity. At the front of the flood surge one can, therefore, observe the unfurling of the upper layers, less dense and more mobile, over the slower, heavier lower layers. Thus, only the upper layers retain an excess of energy which, being able to act only laterally, is used to attack the banks and cause them to crumble. When the flood is at its peak, turbulent erosion, in spite of its impressiveness, appears very limited and is focused on re-suspending the basal sediments. However, eddies with vertical axes, which are generated between faster lines of flow or which are created by irregularities in the channel banks, visibly continue the work of lateral erosion (crumbling of the banks). It is when the water level is falling that vertical erosion is most efficient, thanks to the concentration of flow in the channels and to the lowering of the water level which starts a wave of headward erosion working its way up the tributaries from the trunk stream. The headcut succeeds only in creating channels whose depth does not exceed the thickness of the alluvial material.

The end result of the work of these floods is the creation of enormous plains of lateral erosion — the *plains of lateral corrasion* of JOHNSON — upon which wander ephemeral streams and where the bedrock is covered by only a thin alluvial film which thins out quickly at its edges.

2) Effects of Diffuse Flow — Alluvial plain *sheet-floods* help to spread sediment across the main river bed or playa by means of overbank flow during flooding, thereby helping to erase topographic irregularities. On the alluvial slopes and piedmont slopes, the sheet flows carry away the finest

debris. However, as the redeposition occurring within the channel during flow indicates, the load is so close to the flow's carrying capacity that deepening of the channels is not possible. It is only as the flood waters recede that channels form which evacuate the last of the water. We also note that certain *sheet-floods* are generated, not by water falling directly on the slopes, but by water concentrated further up-slope. It is rare, in fact, that a slope channel — be it a peak or mountain range — continues uninterrupted all the way to the outer edge of the fan. More frequently, the channels disappear abruptly at the level of the fan, splitting into multiple distributary channels (**), and discharge their flow across the entire surface. The result of the action of the *sheet-flood* is thus to sweep the fans and to preclude too thick an accumulation of fine material.

Are active *sheet-flood* events widespread in the area of interest? Although it is only by chance that we can observe them, it is in contrast possible to observe the results and to recognize these outside of the periods of activity. Once such an inventory is fully completed, we will be able to develop a map which shows the actual distribution of *sheet-flood erosion.*

Remember that a surface shaped by sheetflow is almost imperceptibly concave in the upslope to downslope direction. In practice, the surface is an inclined plane whose limits remain undetermined. Upslope, the transverse profile is composed of the juxtaposition of flat/convex elements: the erosional cones at the mouth of hillslope ravines. In contrast, downslope one finds the juxtaposition of flat/concave elements, the river bed created by the convergence of the alluvial fan channels. On the ground, these channels are difficult to see. One is struck, rather, by the isolated, thin deposits found in the shadow of obstacles such as large rocks or tufts of vegetation.

** Note from the translator: The literal translation is goose feet.

Sometimes, as McGee had already noted, one sees a rill, 1 to 2 meters wide and 2 to 3 decimeters deep, which appears and becomes well developed only to disappear 10 to 15 of meters further on. Aerial photographs show a multitude of drainage networks, sometimes lined by vegetation, striking because of the contrast of the light shade of the reworked debris against the darker background of the rocky fan. However, downslope, the channel convergence remains imperfect. The numerous channels remain roughly parallel depending on the steepness of the slope, disappearing into closed depressions on broad evaporation surfaces or, if they are tributaries off a main stem, being abruptly abandoned as the stream down-cuts.

Such features are visible along the entire northwest edge of the Sahara and even into the mountains, in the eastern High-Atlas. In my opinion, most of these fans are still active, but very unequally. Those of the west, where the rains are really quite a bit more abundant, must be more frequently active; those of the east are possibly active less often, but are nonetheless active. In fact, all *sheet-floods* are not of the same magnitude. A slight decrease in the strength of precipitation, a drier or more highly fissured ground, the absence of fine debris playing the role of absorbing layer, reduce the floods to more modest proportions. I have seen some which appeared to barely wet the ground, and others which flowed only several millimeters deep. In addition, if the slope is extremely steep, no *sheet-flood* occurs, probably because the more powerful flow, capable of carrying a greater load or larger clasts, tends to become concentrated. One sees, at the opposite extreme, on soft terraines, the development of *bad-lands* topography (incised terrain).

3) Surface Erosion — The evolution of relief which occurs as we watch represents the combined work of concentrated flow in the thalwegs and diffuse flow on the alluvial slopes and the piedmont slopes. Aside from the

big ergs, we can consider the work of the wind as complimentary or secondary, and often even negligible.

However, concentrated flow and diffuse flow present, under the present climatic regime found on the northwest margin of the Sahara, several common characteristics. First *intermittence* in time and space, which appears fundamental. This allows for the regeneration by physico-chemical erosion of the mantle of fine debris which will be carried away by the next *sheet-flood.* In the bed of the oued, it leaves inactive between two floods, an over abundant load. It produces an irregular pattern of landscape development as one area achieves a stage of advanced planation before another, without in fact exceeding the limits set by the general base level. Second, an *inability to perform linear vertical erosion,* which is a corollary to intermittence since it is a result of the excess load available at the beginning of flow. The vertical downcutting occurs only at the end of the flood when the concentration of flow and increases in stream power allow a larger load to be carried in the drainage channel. This downcutting is local, minor and short-lived because the flow ceases shortly after concentration of flow and does not act below the alluvial cover. Last, *active lateral erosion,* which causes overwidening of the banks, wandering of the channels and distribution of alluvial veneer on the bed.

Diffuse flow and concentrated flow thus act together to plane a surface by removing successive layers of the topography. This is what P. Birot calls *aerolian* [sic] *erosion* and G. Choubert calls *tangential erosion.* Ultimately, this mode of planation leads to a surface distinct from a peneplain formed by *normal* erosion: the *pediplain* of L. C. King.

DISCUSSION

Melle H. ALIMEN: The facts observed from one flood to another depend:

1. on the distance which separates the point of observation from the point of origin of the flood;
2. on whether the flood observed is the first of the flood season or closely follows a previous flood;
3. on the magnitude of the flood.

I observed several floods of the Saoura during the winter of 1950-51, and during the winter of 1951-52 near Beni Abbès. I saw a wall of water, during the first flood at Beni Abbès in November 1951, that is to say from a point relatively close to the Abadla region from which the flood came and at a time when the river bed was dry. The floods which followed in November-December 1951, which occurred on ground saturated with water, did not display the wall of water.

In addition, it appears to me that vertical erosion can exist at the beginning of a flood: here again the characteristics vary with the magnitude of the flood and the position of observation along the thalweg. During the first flood of November 1951, the retaining wall at Beni Abbès was undermined within several minutes. The large cobbles which were carried away the moment the water reached the retaining wall and a crack formed, reveals that vertical erosion was particularly intense. When the flood abated, the water became confined to small channels confined within the preexisting bed but it is not clear that they became entrenched only at the end of the flood.

Mr. Joly: Vertical erosion can, in fact, predominate under certain slope and discharge conditions, especially in the mountains and in the foum. It is possible that local conditions cause downcutting to occur early in a flood event. This did not happen in the case observed; and this appears to be the case in average flows and the general case during low flow in the pre-Saharan oued studied. The channels can begin to incise during the flood but it is as the flood recedes that they appear to become set.

Mr. H. Jaeckli asks about the slope and the velocity of different flows described by Mr. Joly.

Mr. Joly: Slope on the order of 5%. Measurements of velocity not made.

Footnotes:

(1) Institut Scientifique Chérifien, Rabat, Morocco.

(2) G. CHOUBERT (Preliminary note on the Pontien of Morocco, *Bull. Soc. Géol. France*, 5th serie, vol. XV, 1945, p. 729) alludes to *tangential erosion* which is none other than the *sheet-flood erosion* of McGEE (1897), plus the *lateral corrosion* (sic) of D.W. JOHNSON (1931). A. CAILLEUX Liquid flow in sheets and planation, *Rev. Géomorphol. dyn.*, 1950, 243-270) recalls the old observations of GILBERT (1880) and McGEE (1897), unfortunately not familiar enough to french geologists, contrasting them, rather unjustly, to the concepts of DAVIS: and he deservedly devotes a large space to the theories of *pediplanation*, more explicitly formulated by K. BRYAN (1933) and especially by L.C. KING (1947). Already, in 1941, in his Recherche sur l'évolution du relief dans le Massif Central du Grand Atlas (Research on the Evolution of Relief in the Central Massif of the Grand Atlas), J. DRESCH emphasized the role of the erosional slope on the morphologie of the Atlas (p. 627-637). He continues to generalize in J. DRESCH: Sur les pédiments en Afrique méditerranéenne et tropicale, *C. R. Congr. Intern Géogr.*, Lisbonne, 1949, vol.

II(1950), p.19-28. Cf. also F. Joly: Pédiments et glacis d'érosion dans le Sud-Est du Maroc, ibid., p.110-125: and J. DRESCH, F. JOLY and R. Raynal: Évolution des versants et creusement à la bordure nord-occidentale du Sahara, *Bull. Assoc. Géogr. franç.*,, 1951, p.58-63. Refer to C.A. COTTON: Climatic accidents in landscape making, 1947, for a review of the problem.

(3) F. JOLY. -- Phénomènes exceptionnels d'écoulement et d'érosion dans le Sud marocain et la vallée de la Saoura en octobre 1950, *C. R. séances Soc. Sc. Nat. du Maroc*, 1950, p.153-154.

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