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High resolution with small budget: the "GeoDive" method for detailed 3D reconstruction of submerged morphologies and related measurements

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Abstract

The most widespread acquisition methods for lakes and sea bottom geological data are ship-, ROV- or AUV-based; geophysical methods and the related instruments for morpho-bathymetric survey allow to characterize large areas, even at high depths, but with high costs.

It is known that shallow waters can represent a limit for certain vessels and techniques, preventing the acquisition in the nearshore zone.

To overcome the limits, i.e. to survey with high accuracy nearshore shallow waters with a low budget, we tested and tuned the "GeoDive" method that allowed us to survey two test sites, featured by the presence of "block fields" (i.e., accumulations of huge blocks and boulders of gravitational origin) under shallow waters. The "GeoDive" allowed us to map the submerged morphologies and to acquire high-resolution optical images for further photogrammetric processing. The latter was fundamental to obtain 3D high-resolution models, also with conditions of low visibility. An Action Sport Cam (ASC) HD has been used for video acquisition, in addition to the equipment used during scientific diving.

By coupling the processed underwater-acquired data with the direct surveys performed by underwater SCUBA operators, it was possible to perform some morphological and sedimentological measurements and observations on the experimental targets, with the help of suitable markers.

I. INTRODUCTION

The origin of this work is due to the desire to survey and document in detail a submerged morphology detected in the Albano Lake (Latium, Central Italy) using multiple beam techniques in bathymetric campaigns [1]-[5], which had been hypothesized in terms of genesis, but had not yet been observed, documented and measured in detail, directly, by no operator, even in its shallowest part.

One of the main goals of this work has been executed 3D reconstructions, with techniques of Structure from Motion (SfM), with high accuracy and a low budget, using an Action Sport Cam (ACS), especially in shallow water, which can represent a limit for certain vessels and for the most widespread acquisition geophysical techniques. This paper explains the processing steps of the method that we have named "GeoDive", by analogy with the geomorphological research project "Geoswim" carried out at sea using snorkeling surface techniques [6]-[8].

The first part of the work, performed in cold, and often with low visibility, fresh water of volcanic Albano Lake [9], was followed, in a similar way, in less cold shallow coastal marine water, to test the method with better environmental conditions, considering the experience so far accumulated. For this purpose, has been detected, on a smaller scale, a similar submerged morphology in an embayed pocket beach [10] along the Maratea coast (Tyrrhenian Sea, Basilicata, Southern Italy).

II. GEOLOGICAL AND GEOMORPHOLOGICAL SETTING

A. The Albano Lake

The Albano Lake (Fig. 1) is located about 20 km SE of Rome (Italy), 287 m above sea level, and with a depth of 167 meters is the deepest crater lake in Italy; it fills a large, multiple maar depression, the youngest crater of the Colli Albani volcano [11], formed following the most voluminous and recent activity of the Final Hydromagmatic phase [12].

The Colli Albani volcano is part of the high-K Roman Comagmatic Province (Italy), characterized by the superposition of several volcanoes having significant differences in eruptive style, eruption rate and chemistry

[13].

The Colli Albani volcano compositions are dominantly tephritic to K-foiditic [14].

Geomorphological analysis of the subaerial slopes, regarding the gravity-induced landforms, has allowed to recognize the presence of different types of landslides, that are rock fall/topple, rock slide, debris slide, and debris flow [2], [15]; consequently, also gravity-induced morphologies in the submerged slopes have been recognized (Fig. 2), among which subaqueous landslide scars and block fields [2], [4].

The Albano Lake floor shows positive convex landforms considered as landslide debris accumulations, with shape and dimensions largely variable, many of which downslope of a detachment area; also, landslide channels and outrunner blocks are present [2], [4].

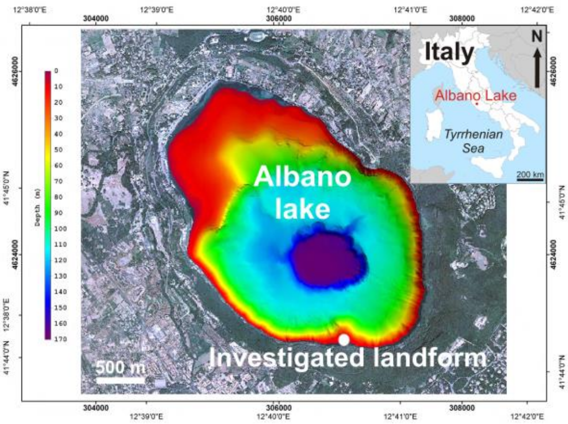

Fig. 1. The Albano Lake, with the bathymetric range shown as colors shades (modified from [5]).

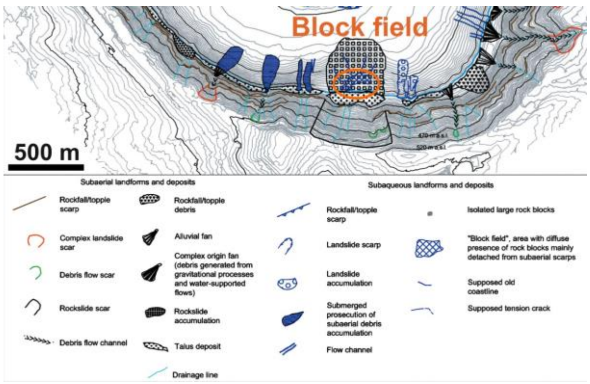

Fig. 2. Excerpt from inventory map of gravity-induced landforms, modified from [2]: investigated block field (orange ellipsis) of the southernmost sector of the Albano Lake crater.

B. Maratea coast

The Basilicata Tyrrhenian coast (Fig. 3) is 20 Km long and is totally located in the municipality of Maratea, the only municipality of the Basilicata Region (Southern Italy) overlooking the Tyrrhenian Sea. This coastal area is geomorphologically characterized by a sequence of promontories and high cliffs, intercalated to a series of gravel pocket beaches [16], [17]. Sandy-gravel deposits that lie along the Tyrrhenian coast of Basilicata are interpreted as relict sediments [18].

The numerous faults in this area is the result of Plio-Quaternary tectonic activity; the coastal slopes present many vertical or sub-vertical rock faces and many systems of discontinuities [19].

Often, the submerged morphologies have a generally quadrangular shape, highlighting the structural control of edging and transversal faults, that have eased the entry of the sea and the relative mechanical action of the water. In some cases, along the edges of the slopes of the coastal shelves, are found collapsing deposits, debris accumulations and accumulation of large blocks [18].

Along the southernmost sector of the coast (from Maratea, to the North, to the Noce River, to the South) the coastal morpho-structures are almost exclusively composed by dolomite sequences belonging to the Bulgheria-Verbicaro units of the Campano-Lucana Platform [20], [21]. The slopes facing the sea, in this area, follow a fault scarp accompanied by the production of detrital deposits [19].

The Maratea coastal area suffer of periodic rockfall events, given the nature of the outcrops present there, which impact along the Maratea SS18 coastal road, a main strategic road in a touristic area [19].

Behind the coastlines, the area of Maratea Valley shows large-scale gravitational phenomena and sagging type morphology [22]-[24].

Fig. 3. Basilicata Tyrrhenian coast of Maratea (cyan line) and Calaficarra pocket beach (from EMODnet Portal for Bathymetry, modified).

C. The block field of Albano Lake

The investigated block field is located along the southernmost sector of the lake (Fig. 2) and its origin is related to subaerial rock fall processes [2]; the underwater survey concerned its right side, as its area is too wide to be fully detected in this context (Fig. 2 and 4). In this area, the block field start directly from the shoreline; the observed blocks, in the bathymetric range 0-13 meters of water depth (from now onwards mwd) have dimensions between decimeters and meters and are all in touch with each other (Fig. 5). Immediately below 13-15 mwd the blocks are no longer in contact; indeed, they are distant from each other, always large (metric dimensions) and increasingly isolated when the depth increases; they almost disappear below 15-18 mwd, where they become sporadic, but however present, until about 20 mwd. In these bathymetric range prevail the finest sediments: from some preliminary analyses carried out between 5 and 12 mwd, the sediment is formed essentially from sand, with more or less gravel, but always with little mud amount.

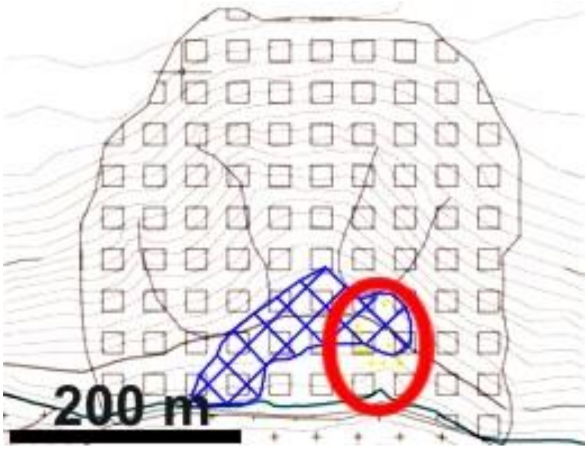

Fig. 4. Albano Lake: surveyed area (red ellipse) which includes the right side of the block field (blue grid); the yellow dots show the GPS detected points (modified from [2]).

Fig. 5. View of the block field on the bottom of the Albano Lake (about 7-8 mwd).

D. The block field of Calaficarra pocket beach

The Calaficarra pocket beach (Fig. 3 and 6) is located along the southernmost sector of the Maratea coast, in the locality of Marina di Maratea; the length of her shoreline is less than fifty meters and the sediments of both emerged and submerged beach are almost exclusively made up of gravel. The bottom of the submerged beach shows two distinct series of bedforms, the first, shallower, between 2-4 mwd and the second, deeper, starting from 7 mwd. In the bathymetric range between 4 and 7 mwd a belt of boulders as a block field (Fig. 7), surrounded by a bed of pebbles and cobbles, separates the two series of bedforms [10]. The blocks, with apparent chaotic disposition, have dimensions between decimeters and meters, such as those observed in the Albano Lake, without reaching its larger size.

The block field was surveyed and simultaneously its outer perimeter was defined using GPS, then mapped (red line on Fig. 6); the straight line marked by letters A, B and C, N-S oriented and 30 meters long, indicates the position on the bottom of the used measure tape used during the video acquired area (Fig. 6). The shape and position of the block field, adjoining the emerging cliff, almost as a continuation, seems to indicate the genesis for collapse and accumulation in place with minimal dislocation of the blocks, in accordance with what is stated in the above-mentioned literature regarding emerging and submerged morphologies.

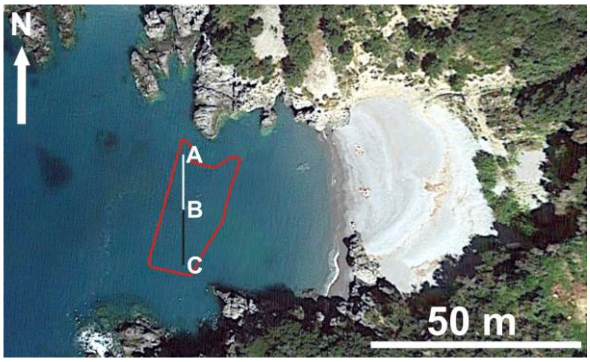

Fig. 6. Calaficarra pocket beach: block field external perimeter (red line) and straight-line indicating the measure tape placed on the bottom.

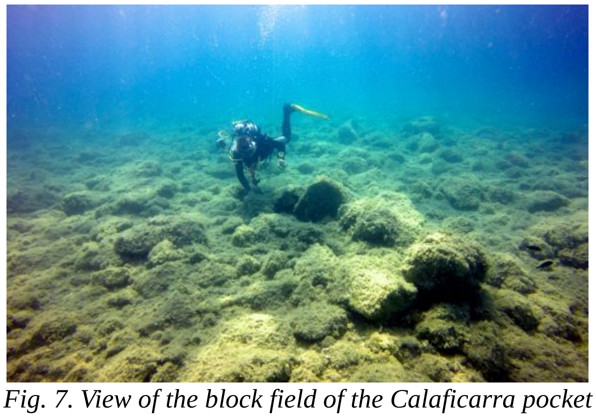

Fig. 7. View of the block field of the Calaficarra pocket beach to 5-6 mwd (modified from [10]).

III. MATERIALS AND METHODS

A. Data acquisition

A series of scientific dives were carried out with SCUBA (Self Contained Underwater Breathing Apparatus) equipment using standard air (EAN 21) as respiratory gas. The first exploratory dives were used to delimit the areas of interest and characterize the substrate from the geomorphological point of view (underwater geological survey).

An ASC able to record video and image up to 4K video resolution (3840x2160 pixels) has been used for video acquisition to map the submerged morphologies and to acquire high-resolution optical images for further photogrammetric processing. The camera was setting using HD resolution (1920x1080 pixels), Ultra-Wide FOV (field of view) which corresponds to a shooting angle of 170 degrees, and an acquisition frequency (frame rates) of 50 fps (frames per second) and a pixel size of 0.26 mm. Camera calibration was required taking into account the setting conditions used, like in other types of cases studies [25], [26], [27], [28].

The most efficient shooting mode for capturing a video, intended for photogrammetric decomposition, and for the three-dimensional reconstruction of a large area, is azimuthal to the subject. Slightest variations of the shooting angle, on the recovery plane, relative to the vertical direction (few degrees, at most 10 degrees per side) help the reconstruction allowing to cover a more complete and accurate shooting range.

No auxiliary light sources were needed during video shooting; indeed, it was verified that the use of artificial lighting, which often does not uniformly cover the framed field, makes video shooting less clear in the subsequent processing phase. In low visibility conditions, finally, the lighting is totally counterproductive, creating diffusion phenomena around the particles present in suspension in the water.

The routes carried out have been done trying to keep constant the depth of the framed seabed and the distance between the scuba operator and the bottom (use of depth gauge and a suitable spacer built on the principle of lead wire), and finally, given the short-traveled distances, the straightness of the route (compass use).

After several tests performed in Albano Lake, the best distance between the scuba operator and the bottom was fixed in 50-60 cm, while at Maratea a nearly double distance was tested (1 m), given the best visibility conditions at sea. At these distances also occurs that the distortion caused by the lens of the Action Cam was almost zero, so it was not necessary to compensate for this defect in post-production.

Artificial markers of known position and size, like numbered bricks (Fig. 8), joined by ribbons, forming a grid, were required and have been prepared for the subsequent correct positioning in the three-dimensional virtual space of the 3D reconstructed model.

The singularity of some boulders, of peculiar shape and size (Fig. 9), have been used on both sites as natural markers like peculiar spot used for the final 3D reconstruction.

Several and necessary GPS acquisitions of artificial markers have been made by two operators; the first on the bottom and the second on the surface; a dive buoy with its related cable held upright by using a ballasted reel, considering the low depths, it was enough to mark the bottom points of interest, according to specifics signals sent [29].

Fig. 8. Artificial markers: brick No. 4 and part of ribbon forming a grid (modified from [9]).

Fig. 9. Albano Lake: a boulder of peculiar shape and size, used on as natural markers (13 mwd).

B. Data processing

Three-dimensional reconstruction of the block fields with SfM techniques starts with the factorization in photo frames of the acquired file video; the Free Video to JPG Converter software was used for extract frames from video files. Images available are not used all, they are enough 10 out of 50 for each second for allow the overlay of 60% between a frame and the next, considered a mandatory factor to be guaranteed the achievement of the 3D reconstruction, made with Agisoft PhotoScan software.

As a rule, the generation of a three-dimensional model passes for three subsequent phases: a *Sparse Cloud* resulting from the alignment of the frames, a reworked *Dense Cloud* (both Points Clouds) and a *Mesh* which returns the surface reconstruction of the objects resulting from the interpolation of the points ensembles. Another useful step to apply in SfM method is the texturization of the meshed model in real colors, derived from the frames used; this can give a most real product of the analyzed area.

The higher is the number of points provided by the *Dense Cloud*, the smaller is the error contained in the relative *Mesh*, and smaller are too the chances of having "bugs" in the resulting surface (Fig. 10).

Sub-models Mesh deriving from 100 frames was made, using the automatic catching markers; the union of two consecutive sub-models was performed with the manual search of markers in overlapping distal areas; the method ensures at least 50 frames in common with the previous one and the following. The resultant alignment of the sub-models allows to mold strips with an overlap, at least, of 20% (Fig. 10).

The passage from the *Dense Cloud* to the *Mesh* could be a hardware limit (RAM and graphic card), because the high numbers of points in each cloud makes difficult to process the continuous information (*Mesh*) even for a high-end level PC.

Finally, the acquired GPS points in correspondence with the artificial and natural used markers enabled the geo-referencing of the models in a GIS environment.

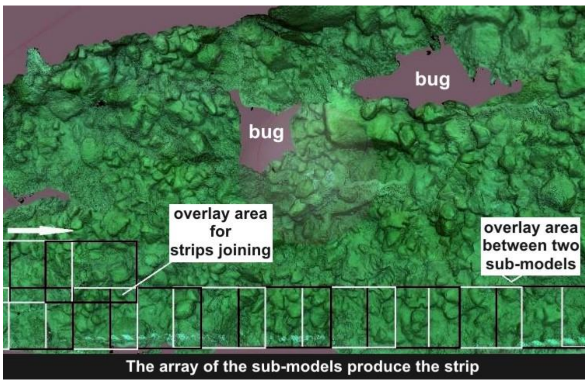

Fig. 10. Overlap of sub-model Mesh and strips generation (modified from [9]).

IV. RESULTS AND DISCUSSIONS

One of the first evidence highlighted by the GeoDive method is that even the video acquisitions made under low visibility can be successively processed with success (Fig. 11 and 12). The 3D reconstruction procedure used returns a kind of augmented (increased) reality without the aid of adjustments in post-production (Fig. 12), which allows to obtain additional environmental information that in some cases cannot be noticed by the observer, even if expert.

In the shooting conditions, used in the Albano Lake and at sea in Maratea, the *Dense Cloud* generated by the software, shows a great detail (Table 1); moreover, a suitable hardware would be able to distinguish objects with dimensions on the order of half a millimeter.

The success of the result obtained is not limited only to the number of points available to create the *Mesh*, but also by properly tracking of the pre-defined routes and maintaining low and constant the displacement speeds, to minimize the presence of bug areas in the final model, as happened in the first models made in the Albano Lake (Fig. 13). The method, also tested in shallow coastal marine water with better environmental conditions, has given well results also keeping a double distance (Fig. 14).

The 3D reconstructed models allow to have an overview of the deposits, and to establish, for subsequent surveys, the location of the areas of greatest interest; considering of this one, some block linear measurements and related volumetric elaborations were performed on the models, and then compare them with the real dimensions detected in place (Fig. 15).

Fig. 11. Real low visibility conditions in Albano Lake during some made dives.

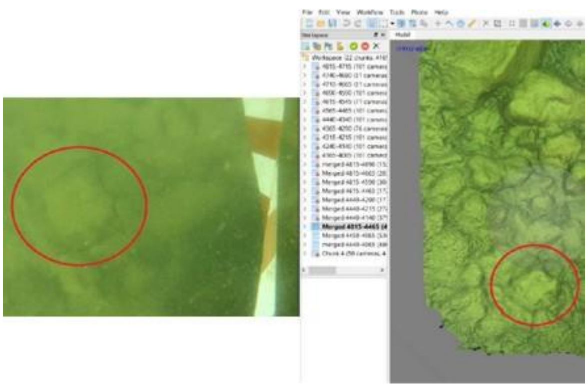

Fig. 12. Comparison of subaqueous view (low contrast and low definition), on the left, and "increased reality" of the Model (high contrast and high definition on the right (modified from [9]).

Table 1. Main 3D Models features.

	Albano 1	Albano 2	Maratea
Area (m^2)	42.7	34.5	54.8
Points (Dense Cloud)	8113000	6555000	19728000
Points/cm^2	19	19	36
Ground resolution (mm)	0.57	0.57	0.83

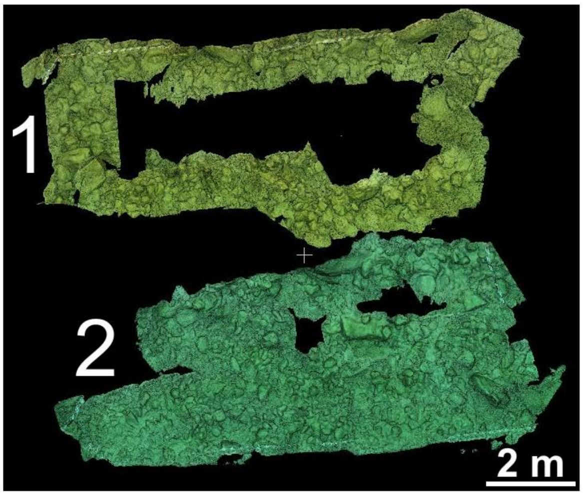

Fig. 13. Albano Lake: two joined model Mesh, with bugs of different sizes (from [9]).

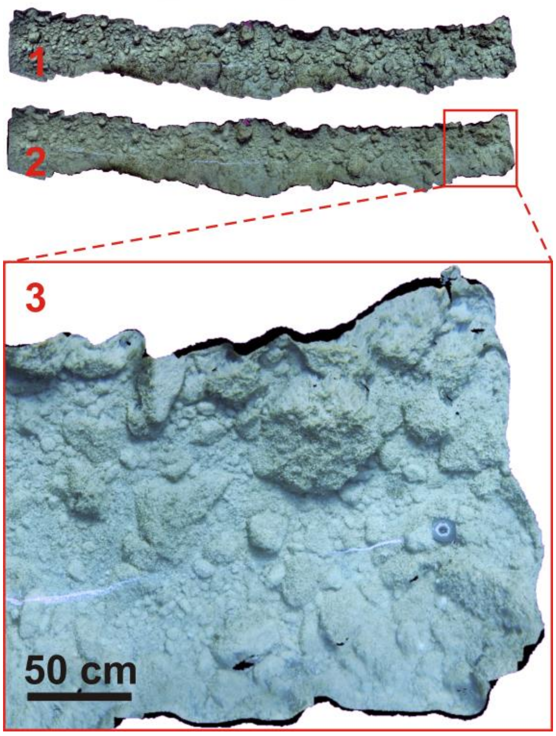

Fig. 14. Maratea 3D model: 1) Mesh Cloud of the AB segment (length 15 m); 2) Texture of the same segment; 3) Magnification of the right section of the texturized segment.

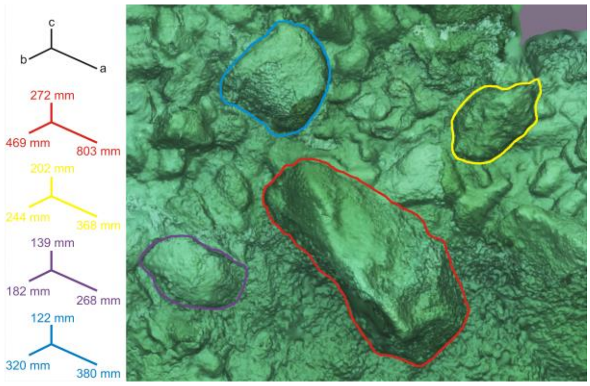

Fig. 15. Some block measurements on the 3D reconstructed model of bottom of Albano Lake (modified from [9]).

V. CONCLUSIONS

The “GeoDive” method has allowed to reconstruct with high accuracy and a small budget 3D models of sections of submerged morphologies, as in the reported cases, consisting of debris accumulations put in place by landslides; the correspondence between the models and the real geological bodies, compared to their real size and features, subject to due verifications and evaluations, was almost perfect.

The use of Action Sport Cam with high technical and optical characteristics, has allowed to have a very detailed final 3D reconstruction, which allows to highlight details that are also not appreciable during the simple observations and video shoot. The created models are very useful for making "dry" considerations and measurements, also for subsequent explorations and sampling. A surprising aspect of the method applied it has been understood that it can be applied successfully even in low visibility conditions.

The surveys conducted in the Albano Lake have allowed to document, for the first time, effecting both video and photo reports, the block field and define that on this right side the blocks extend up to the shoreline; these evidences, taking into account the mentioned literature, have allowed us to assume that the observed bottom morphology could be associated with a more recent landslide event, not yet covered by fine sediments, which partly covers the underlying reported deposit, integrating it. The survey conducted in the Calaficarra pocket beach has allowed to verify the validity of the method under different environmental conditions and, at the same time, modify some of the video capture parameters to compare all the reconstructed models.

Lastly, it is believed that the method developed during the scientific dives can be validly used to characterize undetected bottom morphologies, but also to clarify and/or validate underwater morphologies, in specific points, reconstructed with other indirect methodologies.

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