

PHILIPPINE PATENT [19]**[11] No.: 25998****[45] Issued: JAN 13 1992****[54] Title: CLONING OF DNA FOR PROTOZOAL ANTIGENS****[75] Inventor (s): ANTHONY ARTHUR HOLDER, MICHAEL JAMES LOCKYER, JASBIR SINGH SANDHU, VALENTINA RIVERO-MORENO, all of Kent, England and KAREL GERRIT ODIJK, of Frenkendorf, Switzerland****[73] Assignee (s): THE WELLCOMBE FOUNDATION LIMITED, of London, England****[22] Filed: February 21, 1985****[21] Application Serial No: 31892****FOREIGN APPLICATION PRIORITY DATA****[31] Number (s) : 8404692; 8424340****[32] Date (s) : February 22, 1984; September 22, 1984****[33] Country (ies) : United Kingdom****[52] PH Class 435/68; 435/70; 424/88****[51] Int. Class C12P 21/00; A61K 39/00; A61K 39/02****[58] Field of Search 435/68; 435/70; 424/88
C12P 21/00; A61K 39/00; A61K 39/02****[56] Reference (s) Cited and/or Considered:****WO 85/03725 2/1985****J. Exp. Med. 156 (1982) pp. 1528-38****J. Exp. Med. 158 (1983) pp. 1647-53****[57] A B D T R A C T**

The present invention relates to the cloning of the
1. 195 gene of Plasmodium falciparum and the use of 1. 195
in vaccines for the treatment or prophylaxis of malaria.

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CLONING OF DNA FOR PROTOZOAL ANTIGENS

ABSTRACT

The present invention relates to the cloning of the P.195 gene of *Plasmodium falciparum* and the use of P.195 in vaccines for the treatment or prophylaxis of malaria.

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The present invention relates to a cloned sequence of DNA, and fragments thereof, of Plasmodium falciparum which may be used to provide antigenic peptides for use in malaria vaccines.

5 Malaria is an increasing health problem throughout the third world. Several hundred million people suffer from the disease and the most acute form, caused by the protozoan parasite Plasmodium falciparum, kills over a million children each year in Africa alone.

10 An effective immunity against the asexual multiplication of the parasite in the blood-stream would prevent the clinical disease. Prevention of the ~~in~~-invasion of red blood cells by an effective immune response against the invasive form, the merozoite, should

15 interrupt this cycle.

In a rodent malarial model it has been shown that a protein antigen synthesised within the mature intra-erythrocytic form, the schizont, and expressed on the surface of the merozoite, can be purified and that

20 vaccination with this antigen can generate protective immunity against Plasmodium yoelii (Holder, A.A. and Freeman, R.R. *Nature* 294, 361-364 (1981)). This antigen has an apparent molecular weight (Mw) of 230,000 and is proteolytically processed in vivo such that

25 discrete fragments of the antigen are present on the

merozoite surface (Holder and Freeman, 1981 supra;
Holder, A. A. and Freeman, R.R. Parasitology **80**, 211-
219 (1984a)).

By "molecular weight" is meant the apparent relative
5 molecular weight as determined by polyacrylamide gel
electrophoresis in the presence of sodium dodecyl sulphate and standard molecular weight markers. The molecular weight of the antigenic proteins of the invention may thus be conveniently determined by the techniques described by U.K. Laemmli, Nature, (1970) **227**,
10 680-685. Convenient standard molecular weight markers include, for example, spectrin heterodimer (2.2×10^5
M.W. weight), β -galactosidase (1.16×10^5 M.W.), phosphorylase b (9.3×10^4 M.W.), bovine serum albumin (6.8×10^4 M.W.), aldolase (3.9×10^4 M.W.), triose phosphate
15 isomerase (2.7×10^4 M.W.) and lysozyme (1.5×10^4 M.W.).

When the protein was used to vaccinate mice the protection was adjuvant dependent and it appeared to be provided by a cell mediated effector pathway (Freeman,
20 R. R. and Holder, A. A. Clin. Exp. Immunol., **54**, 609-616 (1983a)), although a monoclonal antibody against the protein has been shown to confer passive protection upon mice (Majariam W. R. et al., J. Immunol., **132**, 3131-3137 (1984)).

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Analogous protein antigens have also been described in other Plasmodium species. A polyvalent antiserum raised against the purified 230,000 MW antigen of P. yoelii cross-reacted by immunofluorescence with the 5 blood stage forms of all other species of Plasmodium tested (Holder and Freeman, 1984a, supra). In Plasmodium chabaudi the antigen was identified by Western blotting as a 250,000 MW species which may also be processed (Holder, A.A. et al., Mol. Biochem. Parasitol., 9, 191-196 (1983)). Monoclonal antibodies specific 10 for the 250,000 MW P. chabaudi protein were shown to confer passive protection against P. chabaudi challenge in mice (Boyle, D. B. et al., Infect Immun. 38, 94-102 (1982)). A monoclonal antibody against a 230,000 MW 15 protein of Plasmodium knowlesi agglutinated merozoites and thereby inhibited parasite invasion of red cells in vitro (Epstein N. et al., J. Immunol. 127, 212-217 (1981)), and this protein of P. knowlesi is processed in vivo to a series of fragments expressed on the merozoite surface (David P. H. et al., Mol. Biochem. Parasitol. 11, 267-282 (1984)).

In P. falciparum, polyvalent antiserum against the P. yoelii 230,000 MW protein antigen cross-reacted with a 195,000 MW antigen (hereinafter referred to as the

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P.195 protein) (Holder et al., (1983) *supra*). The biosynthesis of this antigen, which appears to be a glycoprotein (Howard, R. J. et al., *Mol. Biochem. Parasitol* 11, 349-362 (1984)) takes place within the 5 schizont form of the parasite and at the end of the intra-erythrocytic stage the antigen is proteolytically processed into discrete fragments (Holder, A.A. and Freeman, R. R. *J. Exp. Med.* 156, 1528-1538, (1982); Hall, R. et al., *Mol. Biochem. Parasitol*, 11, 61-80 10 (1984a)). On the surface of the merozoites (released into the serum at the end of the intra-erythrocytic stage), the protein is fully processed, with three discrete fragments of P. 195 having molecular weights of about 83,000, 42,000 and 19,000 being present. These 15 three fragments are the major surface antigens of merozoites and are strongly recognised by human immune serum (Freeman, R.R. and Holder, A. A. *J. Exp. Med.* 158, 1647-1653 (1983b), Holder, A.A. and Freeman, R.R. *J. Exp. Med.* 160, 624-629 (1984b)).

20 The term 'P.195' is used herein to denote a protein of between 1.8 and 2.3×10^5 *M_w* which is localised in the erythrocytic schizont form of a Plasmodium falciparum parasite and which is processed in vivo into discrete fragments of approximately 8.3×10^4 , $4.2 \times$

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10^4 and 1.9×10^4 MW, associated with the surface membranes of the merozoite form of the parasite.

Within P. falciparum P.195 may exhibit some structural polymorphism as detected by the degree of binding of specific monoclonal antibodies or by small differences in its apparent molecular weight (McBride, J.S. et al., *Science* 217, 254-257 (1982); McBride, J.S. et al., *Trans Roy. Soc. Trop. Med. Hyg.* 78, 32-34 (1984); Hall, R. et al., (1984a) *supra*). However, it will be appreciated by those skilled in the art that these antigens are homologous and that differences demonstrated in particular antigenic determinants may not be important in the broader sense of an immune response in an animal. It has been shown that Saimiri monkeys immunised with P.195 were protected against challenge infection (Perrin, L.H. et al., *J. Exp. Med.* 160, 441-451 (1984); Hall, R. et al., *Nature* 311, 379-382 (1984b)).

The term 'epitope' as used herein denotes an immunogenic determinant of an immunogenic molecule, the immunogenic determinant comprising a molecular configuration capable of eliciting a protective immune response in a susceptible animal, when presented in a suitable form.

It will also be appreciated that P.195 is subject to

allelic variation, wherein different strains of P. falciparum express proteins different from, but substantially similar to any one P.195 protein from any one strain.

5 A comparison of the P.195 gene from the P. falciparum strain described herein with the corresponding gene from a strain isolated by Theithong et al. (Theithong, S., Beals, G.H., Fenton, B., McBride, J., Rosario, V. Walker, A and Walliker, D., Trans. Roy. Soc. Trop. Med. Hyg. (1984) 78, 242-245) by Southern blotting showed
10 structural polymorphism detectable by nucleic acid hybridisation (R. T. Schwartz).

15 For the reasons outlined above, it is believed that the P. falciparum P.195, or an antigenic fragment thereof, is of value for use in a blood-stage malaria vaccine.

20 In order to obtain this protein or an antigenic fragment thereof, such as those produced in vivo and which are present on the merozoite surface, in large quantities and in a relatively pure form, it would be desirable to identify the sequence of the DNA in the gene coding for the expression of this protein in P. falciparum. After identification of the sequence, it would be desirable to reproduce the immunologically

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effective parts of the protein molecule, either by cloning this sequence in a suitable vector and expression in a suitable host, or by chemical synthesis of the amino acid sequence corresponding to the identified sequence.

5 We have now discovered that it is possible to clone the DNA sequence that substantially encodes the above described antigen (P.195) from P. falciparum and that the functional antigen or fragments thereof can be obtained by incorporating said cloned DNA into a suitable vector which, in an appropriate host, is capable of expressing the antigen or peptides comprising at least one epitope thereof.

10 According to one feature of the present invention we therefore provide a cloned DNA sequence substantially encoding the P.195 protein of P. falciparum, or peptides comprising at least one epitope thereof.

15 The term 'cloned' is used herein to indicate any DNA sequence that has been substantially synthesised outside of its natural host.

20 The term 'peptide' as used herein pertains to any molecular structure composed essentially of amino acids comprising more than 2 amino acids. It will be appreciated

that P.195 is a peptide by this definition.

It will be appreciated that the DNA sequences of this invention may correspond to naturally-occurring sequences, or they may be related to such sequences by mutation, including single or multiple base substitutions, deletions, insertions and inversions, always provided that the DNA molecule comprising such a sequence is capable of being expressed as a peptide carrying at least one epitope of the P.195 protein of P.
10 falciparum.

The invention will be described in more detail hereinafter with reference to the accompanying drawings in which:

15 Figure 1 shows the base sequence of a stretch of P.
falciparum DNA containing the gene encoding P.195 and the amino acid sequence for which it codes.

Figure 2 illustrates a cDNA restriction map of the P.195 gene.

20 Figure 3 illustrates a restriction map of the P.195 genomic sequence.

Figure 4 illustrates the construction of plasmids used in the course of exemplifying the invention.

Figures 1A to II show (in sequence) the nucleotide

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sequence of the P.195 gene, the amino acid sequence for which it codes and stretches of sequence at either end of the coding sequence. The lower line of each double line of letters represents nucleotides according to convention, while the upper line shows the amino acid sequence for which the open reading frame codes, the letters representing amino acids according to convention. The sequence was determined by methods described herein and it will be appreciated that, while it has been determined as accurately as possible within the margins of experimental error, there may be some variation in the P.195 genetic sequence.

Figure 2 shows the gene, including sequence in the cDNA clones extending beyond either end of the coding sequence, at the top of the figure (thick line) with important restriction enzyme sites marked. All restriction enzyme codes in this figure are according to convention. Other restriction enzyme sites are indicated on parallel lines below, to simplify the diagram.

The blocked-in lines at the bottom of the figure indicate the positions relative to the P.195 gene from which various plasmid inserts derive, all being cDNA inserts except G1, which represents a genomic insert. X and Y indicate the putative 5' and 3' ends of the P.195 coding sequence, respectively.

Figure 3 illustrates a restriction map of the stretch of genomic DNA including the P.195 gene. The scale is in Kbp and takes as its reference point a HindIII restriction site of the P.195 gene indicated by the bold capital H in the figure. The other restriction enzyme sites are coded as follows; E(EcoR1), R(Rsa1), A(Alu1), M(Mbo1), Pv(PvuII), N(Nde1), T(Taq1), B(BamH1) and P(Pst1). The stretches of sequence shown below the restriction map are those that were found to hybridise to the specific clone indicated. The number in brackets is the cDNA clone to which the segment hybridised, the number always corresponding to the relevant pPFC clone. Where there is also a number outside the brackets followed by two of the above-indicated letters, this indicates that the probe used was less than the whole clone, the number indicating the length of the fragment in Kbp and the letters indicate the restriction enzymes used to generate the said fragment.

Figure 4 illustrates the construction of 2 plasmids used to express fragments of P.195 DNA. pURL507 has a number of characteristic restriction sites as indicated in the figure, and characteristic gene functions wherein P_{trp}, trpE are a promoter and anthranilate synthetase I respectively, Amp^R confers ampicillin

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resistance and Tet^R confers tetracycline resistance. pXY460 also possesses characteristic restriction sites as indicated, a promoter, (Ptac) a gene coding for β -galactosidase (lac^Z) and a gene conferring ampicillin resistance, Amp^R .

The above-mentioned DNA sequence may be characterised as having substantially all or part of the sequence shown in Figure 1, subject to the conditions noted above and further subject to considerations of experimental errors consequent upon determining such a sequence.

The above-mentioned DNA sequence may also be characterised as having substantially the restriction maps as shown in Figures 2 and 3, determined as described herein.

The genetic sequence was determined by the chemical cleavage method (Maxam, A., and Gilbert, W., *Meth. Enzymol.* 65, 499 (1980)) or by the dideoxy method (Sanger, *et al.*, (1977) *Proc. Natl. Acad. Sci.*, 74, 5463-5467) after subcloning fragments of the target DNA into the bacteriophage cloning vectors M13mp8 and M13mp9 (Messing, J and Vieira, J, (1982) *Gene* 19, 269-276).

Analysis of the sequence shown in Figure 1 reveals a likely start codon (AUG) at position 216 followed by an open reading frame of a further 1633 codons. The calculated molecular weight of the polypeptide gene product is 187,780. The start codon is followed by a putative signal sequence of 18 codons coding for an amino acid sequence which would be cleaved off the protein before it matures. Nucleotides 448-526 code for alternate repeats of the tripeptide sequences serine-glycine-glycine and serine-valine-alanine occurring within the 83,000 MW fragment of P. 195 (Example 6). The distribution of some of the amino acids within the translated sequence is asymmetric. For example, of the 15 cysteine residues, two are in the putative signal peptide and eight are in the C-terminal 78 amino acids (the 42,000 MW fragment). 11 tripeptide sequences of the structure Asn-X-Ser or Thr (where X can be any of the common amino acids except proline) have been identified which are potential N-glycosylation sites.

The identification and cloning of a fragment of the DNA sequence coding for P.195 may be carried out, for example, as follows. Whole messenger RNA (mRNA) was first extracted from synchronous cultures of P. fal-

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ciperum by treating the cells with detergent, precipitating the mRNA by ethanol treatment and centrifugation and purifying by chromatography on oligo-dT cellulose. The substantially pure product was then used to synthesise copy DNA (cDNA) using reverse-transcriptase and DNA polymerase. After purification, the cDNA was inserted into a plasmid which was then introduced into a host by transformation.

In order to ascertain which clones in the resulting 'library' contained relevant DNA inserts, a probe was isolated by centrifuging P. falciparum mRNA through a sucrose gradient and characterising the fractions by in vitro translation. A fraction found to encode P.195 was rendered radioactive, after limited alkaline hydrolysis, with polynucleotide kinase and $\gamma^{32}\text{P}$ -ATP. Using this probe in a colony hybridisation experiment, several clones were found to hybridise to it, some of them strongly. These were then sorted into families by cross-hybridisation and one of each family was made radioactive by nick-translation with DNA polymerase and α - ^{32}P -dATP. Assuming these probes represent parts of the DNA sequence for P.195, they should hybridise to a mRNA of not less than 5,300 bases long in a total extract of P. falciparum mRNA, as this is the minimum estimated

length of mRNA necessary to code for a protein of 195,000 M_r.

Probes that recognised such mRNA (Northern blot procedure) were then characterised further by incorporation into a vector which, in a suitable host, was capable of expressing the cDNA sequence as a fusion peptide. To ensure expression of this cDNA, the fragments were treated with exonuclease prior to incorporation into the vector in order to give randomised reading frames. Peptides expressed were probed with polyvalent rabbit serum raised against P.195. The DNA fragment referred to above was detected using such a procedure.

With regard to the cloning of full length cDNA for P.195 there are now available several methods for cDNA synthesis to represent the entire mRNA (eg Heidecker, G. and Messing, J. (1983) Nucleic Acid Res. 11, 4891-4906). Cloning may also be carried out by the use of total genomic DNA digest 'libraries' which are prepared readily and the relevant sequence, or fragments thereof, detected in such a library by the use of the above-described fragment as a 'probe' (for example, Odink, K.G. et al., Biochem. Parasitol. (1984) 10, 55-66). A proportion of sequences found

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by this technique may be full length cDNA sequences as required, though many will be fragments of such a sequence. In order to determine which clones in the library represent a part of the DNA sequence desired, a method known as 'chromosome walking' (Hadfield, C., Focus 5, 1-5 (1983) Bethesda Res. Labs) may be employed, which method entails the use of known fragments (probes) to detect other fragments by cross-hybridisation. These freshly located sequences may then, themselves, be used as probes and, in this way, the whole sequence of DNA substantially encoding P.195 may be identified and cloned. Using such procedures, a restriction map characteristic of the DNA sequence may also be prepared.

15 The construction of a physical map of the gene for P.195 in genomic DNA by restriction endonuclease cleavage, gel electrophoresis, transfer to nitrocellulose or polyamide membranes and hybridisation to specific probes derived from the cloned DNA is extremely useful to confirm and facilitate the orientation and position of cDNA and genomic clones. In addition a comparison of the restriction sites within the cDNA clones with those in the genome can be used to detect features of the gene which may not be

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present in the mRNA from which the cDNA is synthesized. An example would be the presence of discontinuities within the coding sequence, introns, which may be spliced out of the transcribed RNA by specific splicing events. One such possible intron of about 5 700 b.p. has been located by the above techniques between nucleotides 221 and 313 of the coding sequence (Fig. 1), that is, between the *Mbo*I(M) and *Hind* III sites at these positions (Fig. 3).

10 As indicated above, P.195 is processed in vivo into discrete fragments including the fragments referred to above. These fragments may prove to be of considerable value in providing immunity against malaria, and the DNA sequences for such fragments represent an 15 important embodiment of the present invention, particularly since such sequences are generally likely to be better capable of expression in suitable vectors than the DNA sequence for the entire protein.

20 Thus, in a further aspect of the present invention we provide a cloned DNA sequence substantially encoding any one of the P.195 fragments occurring in vivo. Those fragments of the naturally occurring P.195 most likely to elicit an immune response in a susceptible

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host are those that are present on the merozoite surface.

In a yet further aspect of the present invention there is provided a cloned DNA sequence substantially 5 encoding any one of the P.195 fragments occurring on the surface membrane of a P. falciparum merozoite in vivo.

To locate the position of the processing fragments (Holder and Freeman, 1984b, supra) In the linear gene 10 sequence, one direct approach is to purify the fragments and determine a partial amino acid sequence which can then be compared with the translated gene sequence. This has proved to be feasible for the 83,000 M_w fragment which appears to be specifically 15 shed from the merozoite, possibly during the process of red cell invasion, and accumulates in the supernatants of in vitro cultures. Sequencing of the 20 amino-terminal residues of the 83,000 M_w fragment of P.195 has also shown that the corresponding coding 20 sequence is located from nucleotides 273 to 332 in Figure 1, thus positioning this fragment within the gene.

The position of the 42,000 M_w fragment was determined by the use of monoclonal antibodies in conventional

manner and is described in Example 7. It has been established that the coding sequences for the 42,000 MW and 83,000 MW fragments are at opposite ends of the gene.

5 Experiments to demonstrate allelic variation in the P.195 gene have shown that the greatest variation occurs in the region 5' to the Hind III site (in the 83,000 MW fragment) and in the 3' non-coding region (Figure 2). The most conserved sequence is at the
10 3' end of the gene corresponding to about 130 amino acid residues at the carboxy terminal of the 42,000 MW fragment, suggesting that this fragment may comprise at least one useful epitope.

15 Thus in a further embodiment of the invention we provide a DNA sequence corresponding to the 42,000 MW fragment of P.195.

The DNA sequence according to the invention may also be used to produce viruses containing the DNA sequence. For example, a strain of vaccinia virus
20 (Tk^-) unable to confer upon infected cells the ability to grow on media not containing hypoxanthine is used to infect a tissue culture. That tissue culture may then be transformed with the P.195 gene, or fragment(s) thereof, linked to a Tk^+ genetic determinant.

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Some of the subsequent viral progeny will have such transforming sequences in the form of inserts in their genomes. These can then be selected by their ability to confer upon tissue culture cells the ability to grow on media devoid of hypoxanthine. Such colonies as do grow are then further selected for production of P.195, or peptides comprising at least one epitope thereof, for example by use of a relevant monoclonal antibody such as F11.2. Such vaccines strains can then be used to infect animals susceptible to malaria, as the new vaccinia strain will cause production of an immunogenic material peptide(s). Thus, in a yet further aspect of the invention we provide a non-pathogenic virus provided with the DNA sequence according to the invention which may be used to provide immunity to malaria in a susceptible vertebrate host.

It will be appreciated that such vaccines are also readily capable of providing immunity to other infections, such as smallpox, diphtheria, hepatitis B, rabies, herpes simplex virus, whooping cough and the like. Thus, the invention also provides a non-pathogenic virus as defined above, further capable of providing immunity to other infection(s) which

may be administered jointly, or individually, together with any other vaccine.

Based on the above-described characterisation of the DNA sequence for P.195, the cloning of any desired fragment of the sequence is possible by reference to the restriction map so gained.

5 The insertion of a piece of foreign DNA into an E. coli gene in the correct reading frame allows the expression of a fusion protein, in which part of the 10 amino acid sequence is derived from the E. coli gene and part of it is derived from the inserted DNA. Suitable expression vectors with appropriate control sequences and convenient restriction sites have been 15 constructed, which allow high levels of expression of fusion proteins.

Thus, examination of the restriction map of the expression system of choice and the sequences to be expressed, together with a knowledge of the translational frame, enables specific DNA fragments to be 20 ligated into the expression vector and expressed, without further manipulation. For example, pWRL507 is a plasmid constructed from pAT153 and the trpE gene (Nichols, B. P. et al., J. Mol. Biol. 146, 45-54 (1981)) with a synthetic EcoRI-Bgl II linker inserted at the

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Dgl II site at nucleotide 1223 in the trpE gene (Figure 4). This vector can be cut with Nde I and EcoRI, EcoRI and BamHI, or EcoRI and Hind III and the small DNA fragment(s) replaced with the 2.7 Kbp

5 Nde I-EcoRI fragment of pPFg1, the 400 bp EcoRI-BamHI fragment of pPFc1028 or 2.4 Kbp EcoRI-Hind III (where the Hind III site is in the polylinker of the plasmid) fragment of pPFc1028, respectively. In addition, specific fragments such as the 1.2 Kbp

10 EcoRI-Nde I fragment of pPFc1028 can be subcloned into the polylinker region of pUC9 (in this instance as an EcoRI/blunt end fragment), then cut out with EcoRI and Hind III and cloned into pRL507 cut with EcoRI and Hind III.

15 By using suitable restriction enzyme sites, DNA fragments from the P195 gene sequence may be cloned into a site within the trpE gene in the correct orientation, but usually in the wrong translational frame. In order to obtain expression of the inserted sequence, a synthetic linker of suitable length can be inserted into the restriction site between the trpE gene and the insert, to give in frame expression of the fusion protein. Alternatively the plasmid containing the inserted DNA can be

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opened at the unique restriction site between the bacterial and the inserted DNA and the DNA treated briefly with the enzyme Bal 31 to remove a few bases from each end of the linearised DNA. After repair 5 with the large (Klenow) fragment of DNA polymerase 1, the plasmid is recircularised with T4 ligase and used to transform bacteria. One in three of the 10 transformants should contain the P.195 sequence in the correct reading frame to be expressed as a fusion protein with the trpE gene product. It will be appreciated by those skilled in the art that the extent 15 of digestion with Bal 31 will determine the final size of the expressed fusion protein and the relative lengths of trpE and P.195 sequences contained within it. In addition, the insertion of a synthetic linker during ligation after Bal 31 digestion and repair facilitates the analysis of particular strains 20 after transformation. By the judicious use of specific restriction enzyme digestion and Bal 31 enzyme treatment, any specific region of P.195 can be expressed as a fusion protein.

Thus, in another feature of the invention is provided a vector, containing a DNA sequence according to the invention tandemly linked to an amino-terminal cod-

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ing portion of a gene translatable by the relevant host and, optionally, any control sequence(s) associated therewith, which, when used to transform a suitable host will result in production of a fusion protein comprising at least a part of P₁₉₅ or a peptide comprising at least one epitope thereof.

5 An alternative method for expressing DNA fragments is to use an open reading frame (ORF) vector into which (usually) short pieces of DNA can be inserted, often 10 within the sequence coding for the N-terminal amino acid sequence of an E. coli protein. The inserted DNA must contain no stop codons in the correct translational frame, be in the correct orientation relative to the direction of transcription, and be in the 15 correct frame at each end. For pieces of DNA from a protein coding sequence generated by a random cleavage method the theoretical probability of read-through in the correct frame is 1 in 18. ORF vectors based on β -galactosidase have been described (Koenen et al., 1982). 20 Insertion of a piece of DNA into a site at the N-terminus of the protein in the correct frame confers read-through expression of the β galactosidase protein which can be detected by hydrolysis of the chromogenic substrate 5-bromo-4-chloro-3-indolyl- β -D-

galactoside (Xgal). For example if Xgal is included in the agar upon which the colonies are grown, transformation of a suitable host strain with a plasmid expressing a functional β -galactosidase will produce a blue colony. One such vector, pXY460, contains the β -galactosidase gene under the control of the tac promoter. Insertion of DNA into the Sma I site may convert the gene to in-frame expression. Transformation of an E. coli host such as JM105 converts the bacteria to ampicillin resistance and expression of the fusion protein can be induced at high levels by the addition of isopropyl- β -D-thiogalactopyranoside (IPTG).

Thus, in an alternative aspect of the invention, we provide a vector comprising a gene capable of translation in a suitable host, optionally provided with relevant control sequences, into which is inserted a DNA sequence according to the invention suitably altered such that the portion of said gene carboxy-terminal to said DNA sequence is correctly translated on expression in a suitable host to produce a fusion protein comprising at least a part of P.195 or a peptide comprising at least one epitope thereof and part of said gene-encoded protein.

The polypeptide coded by part of the P.195 gene in a

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fusion protein may be cleaved from that fusion protein by enzymic or chemical cleavage of the appropriate peptide bond. It will be apparent to those skilled in the art which enzymic or chemical cleavage method should be employed, by examination of the amino acid sequence expressed. By insertion of a synthetic oligonucleotide linker between the P.195 DNA sequence and the bacterial gene sequence in the fusion protein expression system, a suitable site may be provided for enzymic or chemical cleavage between the P.195 sequence and the remainder of the expressed fusion protein. In this way the P.195 gene-encoded fragments may be purified away from host peptides.

Direct expression of the coding sequence for the P.195 protein or parts thereof can be achieved by placing the inserted DNA sequence directly after an AUG start codon in the correct reading frame such that the DNA insert replaces the coding sequence normally transcribed and translated by the bacterial control region. Such a control region includes a promoter and a ribosome binding site in the optimal position relative to the start codon. The DNA sequence to be expressed may be correctly positioned by the use of suitable restriction sites and if necessary by using a suitable synthetic oligonucleotide linker. At the

end of the inserted DNA sequence a stop codon may be inserted in the correct reading frame to stop translation and a terminator sequence to stop transcription may be added. The inserted DNA to be expressed 5 may be the entire coding sequence of P.195 or the entire sequence from which the amino-terminal signal sequence has been removed, or preferably a part of the coding sequence corresponding to an immunogenic fragment of the protein. Suitable fragments may be prepared by restriction enzyme digestion of a suitable 10 cDNA or genomic DNA clone (after examination of the nucleotide sequence), and if necessary further treatment at either or both ends with Bal 31 to digest away in a controlled way parts of the DNA sequence. Controlled digestion is achieved by the selection of 15 proper buffer, temperature, reaction time and amount of enzyme, for example as described in Example 8. At this stage a suitable synthetic linker may be added, preferably by blunt end ligation to the insert, to 20 provide an AUG start codon or facilitate ligation into the expression vector.

According to a further feature of the present invention we provide a method which comprises transforming a host cell with the above-defined cloning vector and 25 culturing the host cell to provide expression of the

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said P.195, or a peptide comprising at least one epitope thereof.

Controlled expression of any cloned fragment will be possible by use of the sequences at either end of the sequence, or by use of other sequences already known. Such sequences include promoters and enhancers. Examples of such promoters include lac, trp, bacteriophage λ PL and hybrid trp-lac(tac). Suitable enhancers include the SV40 enhancer and the enhancer from bovine 5 papillomavirus.

According to a further feature of the present invention we provide a vector containing the above-mentioned DNA sequence according to the present invention.

The vector referred to above may be any appropriate 15 vector which is suitable for the cloning of the DNA and which may be used to transform a host cell and thereby express the relevant protein. Such vectors include plasmids, bacteriophages and cosmids. Vectors which may be used for cloning cDNA include pUC8, pUC9, 20 pAT153, pBR325 and pBR328 for use in Escherichia coli, pOD9 and pKT438 for use in Bacillus subtilis, pMA5G for use in yeast and pAD26SV(A), pSV2-dhfr, SVEHA3 and SVLHA8 for use in mammalian cells.

Vectors for use in expression of the relevant protein

will include control sequences, such as mentioned above. Such vectors include pXY460 and pWRL 507 for use in E. coli or pSV2-dhfr for use in mammalian cells.

5 In a further aspect of the invention, we provide a vector containing the DNA sequence according to the invention, further containing one or more control sequences to regulate the expression of said DNA sequence.

10 Examples of suitable host cells for use in the above-described method may be prokaryotic, such as bacteria (for example E. coli HB101 and DH1, B. subtilis 80170 and IH6140), or eukaryotic, such as yeast (for example XV610-8C yeast cells) or mammalian cells (for example simian CV-1 cells).

15 In an alternative embodiment of the invention we provide a method for synthesising at least a portion of P.195 or a peptide comprising at least one epitope thereof, said P.195 or peptide being optionally covalently linked to further peptide sequence, which method comprises the steps of:

- a) creating a cDNA or genomic DNA library from Plasmodium falciparum;

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- b) selecting a probe for P.195 and rendering the said probe radio-active;
- c) selecting a member or members of the said library by use of the said probe; and
- 5 d) using DNA thus selected from the said library to transform a suitable host which may be used to express the said P.195 or a peptide comprising at least one epitope thereof.

10 The present invention further includes the said P.195 protein or peptides comprising at least one epitope thereof, when obtained by any of the above methods according to the invention. These materials may be incorporated into a vaccine for conferring immunity

15 against malaria. For this purpose the antigenic protein or a peptide comprising at least one epitope thereof may be presented in association with a pharmaceutically acceptable carrier. The antigenic proteins or peptides may be used singly or in combination with other P.195 epitope-containing peptides or

20 with other proteins which will provide immunity against malaria.

In a further aspect there is provided a vaccine for inducing immunity to malaria which comprises an an-

antigenic protein or peptide comprising at least one epitope thereof as hereinbefore defined, in association with a pharmaceutically acceptable carrier.

Pharmaceutically acceptable carriers, in this instance, 5 are liquid media suitable for use as vehicles to introduce the antigen into the patient. An example of such a carrier is saline solution. The antigenic protein may be in solution or suspended as a solid in the carrier, or it may be solubilised by the addition of 10 pharmaceutically acceptable detergent.

The vaccine may also comprise an adjuvant for stimulating the immune response and thereby enhancing the effect of the vaccine. A convenient adjuvant for use in the present invention is aluminium hydroxide.

Conveniently the vaccines are formulated to contain a 15 final concentration of antigenic protein in the range of from 0.2 to 5 mg/ml, preferably 0.5 to 2 mg/ml, most preferably 1 mg/ml. After formulation the vaccine may be incorporated into a sterile container 20 which is then sealed and stored at a low temperature, for example 4°C, or it may be freeze-dried.

In order to induce immunity in vertebrate hosts to malaria one or more doses of the vaccine suitably

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formulated may be administered. It is recommended that each dose is 0.1 to 2 ml preferably 0.2 to 1 ml. most preferably 0.5 ml. of vaccine.

5 There is in a further aspect provided a method for inducing immunity to malaria in susceptible vertebrate hosts, comprising the administration of an effective amount of a vaccine, as hereinbefore defined, to the host.

10 The vaccines may be administered by any conventional by any for the administration of vaccines including oral and parenteral (e.g. subcutaneous or intramuscular) injection. The treatment may consist of a single dose of vaccine or a plurality of doses over a period of time.

15 The following examples are for illustration only and are not intended to limit the invention in any way.

Example 1Identification of a cDNA Clone from the P.195 Gene

20 P. falciparum cultures were maintained and synchronized as described by Holder and Freeman (1982 supra) and cells collected by centrifugation 30-40h. after the last cycle of reinvasion. After washing in PBS (150 mM NaCl, 5mM KCl and 10mM sodium phosphate pH

7.2) the cells were resuspended in four volumes of 50 mM sodium acetate pH 5.5, 100 mM NaCl, 1 mM EDTA and SDS added to 3% w/v. Vigorous extraction with phenol-chloroform (1:1) equilibrated with the same buffer was performed for 5 minutes followed by centrifugation at 16,000 g for 3 minutes. After a second extraction of the aqueous phase, nucleic acids were precipitated with ethanol, centrifuged, the pellet dissolved in 4 ml 0.1 M EDTA pH 7.5 and 4 g CsCl added. The RNA was pelleted through a cushion of 95% (w/v) CsCl in 0.1M EDTA by centrifugation at 150,000 g. for 16 hours at 25°C. redissolved in distilled water and precipitated twice with ethanol.

15 To purify the mRNA, oligo-dT cellulose chromatography was performed by standard methods (Maniatis, T., Fritsch, E. F. and Sambrook, J. (1982), molecular cloning, a laboratory manual. Cold Spring Harbor Laboratory, New York). Size fractionation of RNA in sucrose gradients was as described previously (Udink, K. G. et al., J. Biol. Chem. (1981) 256, 1453-1458). A cDNA library was constructed using standard procedures (Maniatis et al., (1982) supra). cDNA was synthesized in a 50 μ l reaction containing 25 6ug Poly A+ RNA, 5 ug oligo-dT (12-18), 1mM of each

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nucleoside triphosphate, 0.1M Tris-HCl pH 8.3, 10mM MgCl₂, 140 mM KCl, 10 mM DTT and 30 U of AMV reverse transcriptase for 90 min. at 42°C.

Second strand synthesis was in 0.1 ml 0.1M HEPES pH 6.9, 10mM MgCl₂, 2.5 mM DTT, 70mM KCl, 0.5mM of each nucleoside triphosphate and 50 U of E. coli DNA polymerase large fragment for 16 hours at 15°C. After S1 nuclease digestion, 5μg of DNA were recovered and 0.5 μg inserted into the Pst I site of pUC8 (Visser J. and Messing, J. Gene 19, 259-268 (1982) by homopolymeric G-C tailing. E.coli HB101 was used for transformation. Replica filters carrying 3,000 recombinants were probed with ³²P-ATP polynucleotide kinase-labelled 33S mRNA previously shown by in vitro translation to be enriched for mRNA encoding P.195 (Odink et al, 1984). 60 recombinant plasmids were detected with the probe and 12 of these gave a strong signal. On the basis of cross-hybridization of nick-translated inserts, 6 sub-groups were formed from the 12 recombinants. On the premise that these recombinant probes represented parts of the DNA sequence for P.195, they should hybridize to a mRNA of not less than 5,300 bases long from a total extract of P. falciparum mRNA, this being the minimum estimated length necessary to code for a protein of about 195,000 M_w. One member of each group

was labelled by nick-translation and used as a probe on P. falciparum RNA Northern blots. (Thomas, P.S. (1980) Proc. Nat. Acad. Sci. U.S.A. 77, 5201-5). Three recombinants, pFC15, pFC16 and pFC17 with cDNA inserts of 1.6kb, 2.3kb and 1.1kb respectively, hybridized to mRNAs of 9kb, 7.5kb and 5.5kb in size respectively. Isolated insert DNA from pFC17 was treated with exonuclease Bal31 to give randomized reading frames and inserted into an expression plasmid carrying part of the tryptophan operon. DNA was inserted into the Bsh II Site, 13 amino acids from the carboxy terminus of the mature trpE-gene product, anthranilate Synthetase I. In-phase insertion of cDNA into this site gives a fusion protein carrying 56,000 Mw of anthranilate synthetase I. Upon induction of the gene, by tryptophan starvation in the presence of 8-indole acrylic acid, one of the resulting recombinants, pFT 1733, gave a fusion protein of 72,000 Mw (as determined by SDS-PAGE) representing an additional 16,000 Mw encoded by the cDNA insert.

Bacterial extracts and an extract of P. falciparum schizonts were subjected to SDS polyacrylamide gel electrophoresis, transferred to nitrocellulose and then probed with a polyvalent rabbit serum specific for P.195. The fusion protein of pFT1733 was clear-

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ly detected by the antiserum. The antiserum was highly specific for P.195 as, from a total P. falciparum schizont extract, only P.195 was detected. There was no reaction with a bacterial extract containing an 80,000 MW fusion protein consisting of the trpE gene product and a foot and mouth disease virus VP1 protein. In addition, the control using normal rabbit serum showed no binding. Thus, pFC17 encodes some of the antigenic determinants of P. falciparum P.195. Further reference to pFC17 will be by its synonym, pPFc1017.

Example 2

Preparation of Further Overlapping cDNA Clones Related to pPFc1017.

15 A recombinant cDNA library was constructed from size fractionated cDNA. cDNA, prepared and tailed as described in Example 1, was centrifuged through a 5 ml 5% to 20% (w/v) sucrose gradient in 25mM Tris HCl pH 7.4, 100 mM NaCl, 2.5mM EDTA for 3.5 hrs at 45,000 rpm in an SW50.1 rotor (Beckman Instruments). cDNA in the 2 kbp to 8 kbp region (about 100 ng) was harvested, annealed with 300 ng dG-tailed Pst 1 digested pUC9 and used to transform DH1 cells to ampicillin resistance. 1200 recombinants were obtained on 6 agar

5 plates. Replica filters were probed with the insert DNA from pPFc1017 which had been labelled by nick translation. Eleven clones were indentified as containing DNA hybridising to this probe. These clones were numbered pPFc1001 to 1011. This library was subsequently rescreened using a part of the insert in pPFc1007 which did not cross-hybridise with pPFc1017. A further 8 clones, pPFc1028 to 1035, were isolated which hybridised to this probe.

10 15 A further cDNA library was constructed using 100 ng dG-tailed cDNA, annealed with 100 ng G-tailed pUC9 and transformed into DH1 cells. About 6000 recombinants were obtained and these were screened on replica filters with the 340 bp Hind III-Pst 1 fragment from pPFc1017. Clones pPFc1013 to 1016 and 1018 to 1027 which hybridised to this probe were picked and purified. This library was also screened with the pPFc1007 derived probe and a further 11 colonies numbered pPFc-1036 to 1046 were picked.

20 Plasmid DNA from these cDNA clones was purified by centrifugation on caesium chloride gradients and characterized by restriction enzyme mapping and cross-hybridisation. The cDNA clones were aligned in an overlapping linear sequence. The positions of the

six cDNA clones used in the sequence analysis are shown in Figure 2.

Example 3

Isolation of Genomic Clone pPFgl from the P.195 gene.

5 100 µg *P. falciparum* DNA (prepared according to the method of Odink et al., (1984) *supra*) was digested to completion with Hind III, the sample loaded on a 10-40% sucrose gradient containing 1M NaCl, 20 mM Tris, HCl, pH 8.0, 5mM EDTA and centrifuged in a Beckman SW27 rotor for 24 hrs at 26,000 rpm, 20°C. 0.5 ml. fractions were collected by bottom puncture of the tube and aliquots of alternate fractions were run on a 1% agarose gel. Fractions in the region of the gradient giving a positive signal on dot blot hybridization with nick-translated pPFcl017 were digested with EcoRI and ligated with gel-purified Hind III + EcoRI cleaved pUC8 DNA. About 400 transformants in DH1

10 from each fraction were screened on nitrocellulose filters by colony hybridisation with pPFcl017 insert (Grunstein, M. and Hogness, D., *Proc. Natl. Acad. Sci.* **72**, 3961 (1975)). One colony from fraction 39 gave a positive signal. This recombinant, pPFgl, contains a 3.1 kb Hind III-EcoRI fragment which co-migrates with the corresponding genomic DNA fragment, and both have the same restriction enzyme maps. A restriction map

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of pPFg₁ was obtained by partial end-label mapping of pPFg1 insert (Smith, H.O. and Birnstiel, M. L., Nucl. Acid Res. 3, 2387 (1976)). Sequencing was performed by the Sanger dideoxy method described in

5 Example 5.

Example 4

Construction of a Map of the P 195 gene in P. falciparum DNA

P. falciparum DNA was prepared as described (Odink
10 et al., (1984) *supra*) and aliquots of it were re-
stricted with specific endonucleases, either individual-
ly or on some occasions as a double digest, i.e. with
two restriction endonucleases. The products were
electrophoresed on agarose gels (0.7% to 1.5%) in
15 Tris-Borate-EDTA (pH 8.2) containing 0.5 µg/ml
Ethidium bromide and together with DNA fragments of
known length as size markers in parallel tracks. The
DNA was transferred to Gene Screen Plus (New England
Nuclear/Dupont) by a capillary blot procedure and hy-
20 bridised to ³²P-labelled probe DNA at 42°C. in the pre-
sence of 50% formamide, according to the protocols
suggested by the manufacturer. Hybridised probe DNA
was detected by autoradiography at - 70°C. using X-
omat S film between Cronex Lightning-Plus screens.

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The probe DNA was specific plasmid DNA or specific sequences excised from the cDNA or genomic DNA plasmid clones, and purified by agarose gel electrophoresis and elution. The DNA was labelled with ^{32}P by nick translation with E. coli DNA polymerase in the presence of ^{32}P d-ATP. An analysis of the size of restriction fragments from within the genomic DNA hybridising to specific probes enabled a linear map of restriction enzyme sites to be constructed. Such a map of the P₁₉₅ gene is shown in Fig. 3 with some exemplary sites and probes to which the specific fragments hybridised. It will be appreciated that several other specific digests of genomic DNA were performed and were probed with other specific fragments from the cloned DNA, and the results were consistent with the map shown in Fig. 3. To improve clarity of the map, not all of the restriction sites present in the DNA sequence are indicated.

An examination of the genomic map and the restriction enzyme map derived from the DNA sequence indicates that these two are colinear in the region corresponding to the coding sequence for the protein, to the right hand side of the Hind III site at nucleotide 313. However, there appears to be an additional 700 bp of sequence in the genomic DNA, not present in the

cDNA clones, located between the *Mbo* I site and the *Hind* III sites at nucleotides 221 and 313 in the cDNA sequence. This may represent an intron in the very start of the coding sequence.

5 The sites shown on the map are some of those for the enzymes A (*Alu*I), B (*Bam* H₁), E (*Eco*RI), H (*Hind* III), M (*Mbo*I), N (*Nde*I), P (*Pst*I), Pv (*Pvu*II), R (*Rsa*I) and T (*Taq*I). The probes were either total plasmids or specific fragments derived by digestion with specific enzymes at sites within the insert or within the plasmid polylinker region.

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Example 5

Nucleotide sequence of the DNA coding for P₁₉₅

Sequence analysis of the DNA was done using the chemical cleavage method of Maxam and Gilbert (Maxam and 15 Gilbert, 1980, *supra*) and the dideoxy procedure of Sanger (Sanger et al., 1977, *supra*).

1. Chemical cleavage

The DNA fragments suitable for sequence analysis were 20 prepared as follows.

- a) The DNA was digested with restriction endonuclease (under the conditions described by the suppliers), then calf intestine alkaline

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phosphatase (Boehringer Mannheim) was added to the mixture and the reaction continued for 30 min. at 37°C. The DNA was extracted with chloroform and ethanol precipitated. The 5' ends of the DNA were labelled with $[^{32}\text{P}]$ using polynucleotide kinase as described by Maniatis (Maniatis *et al.*, 1982, *supra*). The labelled DNA was cut with a second suitable restriction endonuclease and the mixture was loaded onto 1% (w/v) agarose gel, the DNA bands of interest were electro-eluted from this agarose gel and their sequences were determined.

b) Fragments of DNA were also prepared by modification of the procedure described in section a). The DNA was digested with restriction endonuclease, phosphatase and labelled at the 5' end with $[^{32}\text{P}]$ as outlined above. The DNA fragments were then denatured by addition of de-ionized formamide (final concentration 70% (v/v)), and heated to 100°C. for 5 minutes. The samples were quickly cooled in iced water and immediately loaded onto a non-denaturing 15% polyacrylamide gel (with acrylamide to bis-acrylamide ratio of 60:1 (w/w)). The separated

DNA strands were electro-eluted from the gel
and sequenced.

2. Dideoxy sequencing

The DNA templates were prepared by subcloning fragments of the insert in the filamentous phage cloning/sequencing vector M13mp8 (Messing and Visira, 1982, 5 supra). The sequencing was performed using a synthetic universal primer (Celltech) and [35 S]-d ATPdS (Amersham International) as described by Sanger et al., 1977, supra. Two basic strategies were used to sequence specific fragments. In the first, specific 10 restriction fragments (produced by digestion with RsaI, HinfI, RsaI-Aha III, TaqI) were purified by electro-elution, and where necessary, the staggered ends made blunt using the Klenow DNA polymerase I fragment. Fragments difficult to clone or sequence by the 15 above protocol were treated with Bal-31 (Maniatis et al., 1982). Conditions (DNA and enzyme concentration) were chosen such that 100-150 bp DNA was removed from 20 each end of the fragment in 1 minute at 30°C. By digesting over a time course a series of overlapping fragments were obtained. Bal-31 treated DNA was repaired with DNA polymerase I Klenow fragment. DNA was 25 ligated with phosphatase-treated SmaI-digested M13mp8 (Amersham) and transfected into JM103 or JM101 (Mess-

ing, J., et al., Nucl. Acid Res. 9, 309 (1981)).

Template DNA was prepared according to standard procedures. Wherever possible, sequence was obtained from both strands of each clone.

5 The total sequence obtained by overlapping the sequences of the individual clones is shown in Figure 1. The clones used to determine the sequence are shown beneath the restriction map obtained from the DNA sequence in Figure 2.

10 Example 6

Purification of the 83,000 MW Fragment from Culture

Supernatants and the Determination of a Partial Amino Acid Sequence

15 Supernatants from in vitro cultured *P. falciparum* (described in Example 1) were harvested and centrifuged at 100,000 g for 45 minutes to remove cellular debris. To each 100 ml culture supernatant was added 1 ml 1M Tris, 100 mM EDTA, 100 mM EGTA, 1 ml 100 mM PMSF, 1 ml 0.5M iodoacetamide, 1 ml 10 mM TLEH and 20 0.5 g sodium deoxycholate. The pH was adjusted to 8.2 with HCl and then the sample was centrifuged at 100,000 g for 45 minutes. The supernatant after centrifugation was then applied to a 10 ml column of an-

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5 antibody 89.1-Sepharose (prepared as described by Helder and Freeman, 1984b supra) which had been pre-equilibrated with 10 mM Tris-HCl pH 8.2 containing 1 mM EDTA; 1 mM EGTA and 0.5% (w/v) sodium deoxycholate (equilibration buffer). After the column had been washed extensively with equilibration buffer, material retained on the column was eluted with 50 mM diethyleamine HCl, pH 11.5, containing 0.5% (w/v) sodium deoxycholate. The eluate was concentrated by ultrafiltration using an Amicon XM50 filter and adjusted to pH 8.2. The major polypeptides in the eluate was the 83,000 MW species, and it was the only component which reacted with either monoclonal antibody 89.1, rabbit polyvalent anti-P.195 serum or human P. falciparum immune serum, on Western blots. The major contaminant in the preparation was IgG which was removed from the concentrated eluate by passage through a Protein A-Sepharose column (0.9 x 10 cm) (Pharmacia Fine Chemicals) equilibrated as described above. The unretarded material, depleted of IgG, was collected. Sodium guanidinium chloride was added until a clear solution was obtained and then the protein was reduced and S-carboxymethylated (Waxdal M. J. et al., Biochemistry 7 1959-1966 (1968)). The reduced and S-carboxymethylated 83,000 MW polypeptide was finally

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purified by passage through a column of Sephadryl S300 (Pharmacia Fine Chemicals, Sweden) equilibrated with 10 mM Tris HCl pH 8.2, containing 1mM EDTA, 1mM EGTA and 6M guanidinium chloride. Fractions were assayed spectrophotometrically at 280 nm and by SDS-PAGE analysis of aliquots, and those containing the 83,000 MW species were pooled. After extensive dialysis against water and 5% (v/v) formic acid the sample was freeze-dried, prior to application to the automatic sequencer in a small volume of 5% formic acid. The protein was subjected to 20 cycles of automated Edman degradation in a Beckman 890C sequencer equipped with a Sequamat P6 autoconverter and a Sequamat SC-510 program controller using a 0.33M Quadrol program, as described by Baccanari D. P. *et al.*, J. Biol. Chem. 259, 12291-12298 (1984). The released phenylthiohydantoin derivatives of amino acids were identified by reverse-phase HPLC and confirmed by back hydrolysis (Baccanari *et al.*, 1984 supra). Starting from 910 ml of culture supernatant, 5.9 mg of protein was present in the eluate from the affinity column, 2.6 mg of protein passed through the protein A-Sepharose column and 400 μ g of purified protein was subjected to the Edman degradation.

25 The following partial amino acid sequence was obtained

from the successive cycles of degradation starting at the N-terminal amino acid of the polypeptide.

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	
N.I.	N.I.	N.I.	N.I.	N.I.	Tyr	Gln	Glu	Leu	Val	
5	11.	12.	13.	14.	15.	16.	17.	18.	19.	20.
	Lys/	Lys/	Leu	Glu	Ala	Leu	Glu	Asp	Ala	Val
	Pha	Pha								

10 The residues at positions 1 to 5 were not clearly identified (N.I.) and lysine and phenylalanine derivatives were not separated from each other in the HPLC system employed.

15 By examination of the nucleotide sequence derived from the cDNA and genomic DNA clones it can be seen that this sequence of residues (6 to 20) corresponds to the translated sequence of nucleotides 228 to 332.

20 On this analysis the 83,000 M_r fragment is derived from the amino terminal sequence of the P-195 precursor. In the complete sequence the AUG (methionine) start codon at nucleotide 216 is followed by nucleotide sequence of 18 amino acids which may correspond to a signal sequence present on the primary translation product for many membrane or secreted proteins, and which is normally cleaved off during the passage of the protein into the lumen of the endoplasmic reti-

culum (Kreil, G. Ann Rev. Biochem 50, 317-348 (1981)).

Example 7

The Reaction of Antibodies with Processing Fragments of P.195 and the Position of these Fragments within the Linear Coding Sequence.

By direct amino acid sequencing, the amino-terminus of the 83,000 MW fragment has been located close to the amino terminus of P.195 (Example 6). The other fragments produced by in vivo proteolytic processing can be located in the linear gene sequence by an analysis of the sizes of polypeptides recognised by specific antibodies (preferably monoclonal antibodies) raised against P.195. Two monoclonal antibodies were used in this analysis. Antibody 89.1 (Holder and Freeman, 1982, supra) reacts with intracellular P.195 in schizonts and with the 83,000 MW fragment on the merozoite surface. It does not react (by immunofluorescence) with the subsequent ring stage of the parasite, consistent with the loss of this fragment during merozoite invasion of red cells. Antibody 111.2 reacts with intracellular P.195 in schizonts, with the merozoite surface and with the ring stage parasite by immunofluorescence. This specificity is similar to that of monoclonal antibody described recently by Hall et al. (1984a,

supra).

P.195 and processing fragments of it can be labelled in vitro by the addition of ^{35}S methionine to cultures of the parasite in methionine-free medium (Holder and Freeman, 1982, supra, Freeman and Holder, 1983, supra). The processing fragments on the surface of naturally released merozoites can be labelled by radio-iodination with ^{125}I iodine using lactoperoxidase as described (Freeman and Holder, 1983b supra; Holder and Freeman 1984b, supra).

From detergent extracts of ^{35}S methionine-labelled schizonts a rabbit polyvalent antiserum against P.195 immunoprecipitated P.195 and fragments which have molecular weights of 153,000; 110,000; 83,000; 45,000; 15 42,000 and 29,000 as determined by SDS-PAGE analysis. On non-reducing gels (in the absence of dithiothreitol) the 45,000 and 42,000 M_w species migrated with apparent molecular weights of 38,000 and 36,000 respectively. Antibody 89.1 immunoprecipitated P.195 and 20 153,000, 110,000 and 83,000 M_w species. Antibody 111.2 immunoprecipitated P.195 and the 45,000 and 42,000 M_w species.

From detergent extracts of surface-labelled merozoites the polyvalent anti-P.195 serum immunoprecipitated

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three fragments which have apparent molecular weights of 83,000, 42,000 and 19,000. The 83,000 MW fragment was immunoprecipitated by antibody 89.1. Antibody 111.2 immunoprecipitated the 42,000 and 19,000 MW species. An analysis of these fragments by peptide mapping showed that they were probably non-overlapping pieces of P.195 (Holder and Freeman, 1984b supra).

Based on these data and that described in Examples 6 and 10 the linear order of the fragments within the P.195 coding sequence can be determined. The amino acid sequence determined for the amino terminus of the 83,000 MW fragment corresponds to the sequence at the 5' end of the coding region of the gene, immediately after the presumptive signal sequence. Therefore the 83,000 MW fragment is derived from the amino terminal 42% of P.195. The major intermediate processing fragment of 153,000 MW which is recognised by antibody 89.1 and not by antibody 111.2 is derived from the amino terminal 78.5% of the coding sequence, and therefore including all of the 83,000 MW fragment. The 42,000 MW fragment is derived from the carboxy-terminal 21.5% of the coding sequence, since the antibody 111.2 does not react with the 153,000 MW fragment. The 19,000 MW fragment is presumably located within the sequence of the 153,000 MW species, but not within the 83,000

Mu species.

Example 8

Expression of P195 sequences as Fusion Proteins in E. coli and Purification of the Products

5 In separate experiments, pWRL507 (Fig. 4 of the accompanying drawings) was digested with NdeI and EcoRI, EcoRI and BamHI or EcoRI and Hind III and the relevant fragments purified by agarose gel electrophoresis. This DNA (0.1 pmoles) was ligated with 0.5 pmoles of the DNA fragments derived from the P195 recombinants by the relevant pairs of restriction enzymes and then used to transform DH1 cells to ampicillin resistance. Colonies were screened by restriction enzyme digests of small plasmid preparations. Strains with plasmid containing the insert were further grown in M9 minimal medium containing 100 μ g/ml ampicillin and 10 μ g/ml indole acrylic acid (induced expression) or 100 μ g/ml ampicillin and 10 μ g/ml tryptophan (non-induced). Bacteria were harvested by centrifugation 10 at 10,000 g for 1 minute and then lysed by the addition of SDS sample loading buffer for PAGE (62.5 mM Tris-HCl pH 6.8 containing 2% (w/v) sodium dodecyl sulphate, 10% (v/v) glycerol, 0.1 M dithiothreitol and 0.005% (w/v) bromophenol blue). Aliquots were subjected to

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analysis by SDS-PAGE and then the gels were stained with coomassie blue to detect total protein or the resolved proteins were transferred to nitrocellulose and used for Western blotting with a polyvalent anti-serum raised against purified P.195. A strain containing the Nde I - EcoRI fragment of pPFgl produced an inducible fusion protein of 135,000 MW which could be detected in lysates by coomassie blue staining and by reaction with the polyvalent antiserum. This corresponds to a fusion protein containing 233 amino acids from the N-terminus of the trpE gene product and 907 amino acids from P.195. A strain containing the EcoRI-BamHI fragment of pPFcl028 produced a fusion protein of 53,000 molecular weight containing 326 amino acids from trpE and linker and 155 amino acids from P.195. A strain containing the EcoRI-Hind III fragment of pPFcl028 produced a fusion protein of 105,000 MW consisting of 326 amino acids from trpE and linker and 574 amino acids from P.195. A strain containing the EcoRI-Nde I fragment from pPFcl028 produced a fusion protein of 85,000 MW consisting of 326 amino acids from trpE and 400 amino acids from P.195. In each case the fusion protein was detected by coomassie blue staining and reacted with the poly-

valent anti-P.195 on Western blots. A 750 bp *Rsa* I Hind III fragment derived from the cDNA clone pPFc1013, comprising nucleotides 863 to 1613 together with a G-C tail and part of the pUC9 polylinker region from the 5 *Pst* I site to the Hind III site was sub-cloned into the plasmid pUC9 which had been cut with Hind II, treated with calf intestinal phosphatase and further digested with Hind III. The insert was subsequently cut out of pUC9 using EcoRI and Hind III and inserted 10 (in the correct orientation) into pRL507 cut with EcoRI and Hind III. To obtain inframe expression, 5ug of the plasmid was treated with EcoRI restriction enzyme to linearise the construct. The DNA was precipitated with ethanol, redissolved in 50 μ l H₂O containing 500 μ g/ml BSA and then mixed with an equal volume 15 of *Bal* 31 buffer (Maniatis *et al.*, (1982) *supra*). The DNA was digested with 0.02 units of enzyme *Bal* 31 (Biolabs) for 1 minute at 30°C and then the reaction was terminated by the addition of 20 μ l 1M Tris 100mM EDTA 20 100mM EGTA. The DNA was purified by agarose gel electrophoresis, and then treated with DNA polymerase I large fragment (Klenow) in the presence of nucleotide triphosphates using 2.5 units of enzyme (Boehringer/Mannheim) in a final volume of 50 μ l nick translation 25 buffer (Maniatis *et al.*, (1982) *supra*) for 90 minutes

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at room temperature. The DNA (0.1 pmole) was then recircularised by incubation overnight with 200 units T4 DNA ligase (Biolabs) at 7°C, and then used to transform DH1 cells to ampicillin resistance. Ten individual transformed strains were screened by restriction enzyme analysis of the plasmid DNA. One group of 8 transformants contained plasmids which had lost the EcoRI site. This group was further analysed by growth in M9 medium in the presence of indole acrylic acid or tryptophan. One strain produced a fusion protein of approximately 65,000 MW when grown in the presence of indole acrylic acid, and this fusion protein reacted with polyvalent anti-P.195 serum on a Western blot.

15 In a similar manner the Nde I-Hind III fragment from pPFC1028 (where the Hind III site is the plasmid polylinker) was first subcloned as a blunt end-Hind III fragment into pUC9 that had been cut with Hind II and Hind III. After inserting this fragment into pURL507 cut with EcoRI and Hind III, the new construct was reopened with EcoRI, treated with Bal 31 and then recircularised as described above. One strain produced a fusion protein of approximately 56,000 MW which was detected on Western blots with anti-P.195 serum,

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and containing the C-terminal 170 amino acid sequence of the coding region for the P.195 gene.

Relatively pure preparations of the individual fusion protein were produced from cell lysates. A single colony from a strain was grown up overnight at 37°C. in 100 ml M9 medium containing 50 µg/ml ampicillin. The following day the overnight culture was diluted with 400 ml M9 culture medium containing 50 µg/ml ampicillin and 10 µg/ml indole acrylic acid and incubated for 5 hrs at 37°C. The bacteria were harvested by centrifugation at 6000 g for 10 minutes. The bacterial pellet was suspended in 10 ml 25mM Tris pH 8.0 containing 1mM EDTA, 1 mM PMSF, 0.2% (v/v) NP40 and 1 mg/ml lysozyme and left on ice for 2 hrs. After this time 20 µl of 1M MgSO₄ and 200 µl of 1 mg/ml DNase were added and the sample was left to incubate for a further 2 hrs on ice. The insoluble material was harvested by centrifugation at 20,000 g for 10 minutes and the supernatant (S1) was retained. The pelleted material was washed by suspension in 10 ml 50 mM Tris-HCl pH 8.0 containing 5mM EGTA, 5mM EDTA, 1 mM PMSF and 1% NP40. The material was centrifuged at 20,000 g for 10 minutes and the supernatant was retained (S2). The pellet was resuspended in 10ml 50mM Tris HCl pH 8.1,

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5mM EGTA, 5mM EDTA, 0.5M KSCN, and then centrifuged at 20,000g for 10 min. to yield a third supernatant (S3) and a pellet fraction (P). The pellet fraction was resuspended in 10ml H₂O with and without the 5 addition of 0.1% (w/v) sodium dodecyl sulphate, to solubilise the material and then dialysed extensively against 0.89% NaCl. Aliquots of each supernatant and pellet fraction were analysed by SDS-PAGE and coomassie blue staining and by Western blotting. In instances where there was a high level of expression of 10 fusion protein, this procedure resulted in a final pellet fraction that contain predominantly the fusion protein and therefore constituted an effective purification of the fusion protein. In instances where 15 the level of expression was lower, the fusion protein was present in both S1 and P fractions.

Two Dds 1 Fragments from pPFcl028 corresponding to 20 nucleotides 2961 to 4751 (1790 nucleotides) and nucleotides 4750 to 5125 (375 nucleotides) were purified by agarose gel electrophoresis, treated with 0.04 units of Bal 31 nuclease at 30°C. for 2.5 minutes and then repaired with the Klenow Fragment of DNA polymerase I

as described above. The DNA was ligated into pXY460 which had been cut with Sma I and treated with calf alkaline phosphatase and this was then used to transform JM105 cells to ampicillin resistance. Transformants were plated onto Agar plates containing Xgal and resultant blue colonies were picked. Strains obtained in this way were screened by restriction enzyme analysis of the plasmid DNA, Coomassie blue staining and Western blotting of lysates from cells grown in the presence of IPTG. Strains containing the large Ddel fragment all produced a large fusion protein which reacted with the rabbit polyvalent anti-P.195 serum. 10 strains containing the smaller Ddel fragment were investigated as described but only one appeared to produce a fusion protein which was significantly larger than wild type β -galactosidase and this fusion protein reacted with the rabbit anti-P.195 serum. Although the remaining strains contained the insert the gene product was the same size as the normal β -galactosidase and did not react with the rabbit anti-P.195 serum. The one strain that produced a fusion protein contained an insert of 310bp which covers the C-terminal region of the protein.

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Example 9Direct Expression of P.195 Sequences in E. coli

The EcoRI-Nde I and EcoRI-Hind III fragments derived from pPFc1028 were inserted into pWRL507 as described in Example 8, and were expressed directly by replacing the Pst I-EcoRI fragment in the trpE expression plasmid by the Pst I-EcoRI fragment from pXY460 (Figure 4). In this construction the trp control region and coding sequence are replaced by the trp control region (de Boer, H.A. et al., Proc. Natl. Acad. Sci 80, 21-25 (1983)) and an AUG start codon. Directly expressed products were detected in cell lysates by Western blotting with antisera raised against purified P.195. The direct expression products from these two constructions had apparent molecular weights of 47,000 and 70,000 respectively.

Example 10Analysis of the Immunogenicity and Antigenicity of the Fusion Proteins Produced in E. coli

A rabbit polyclonal antiserum specific for the P. falciparum derived P.195 was obtained by immunising a rabbit with 100 µg of the protein in Freund's Complete Adjuvant (FCA, Difco Laboratories, Detroit) and then boosted with 100 µg of the protein in Freund's incomplete adjuvant (FIA) on days 22, 43 and 211. On day 218 after the primary immunisation the serum was collected.

Polyvalent antiserum was produced by immunization with the purified fusion proteins (Example 8). Rabbits were immunized subcutaneously with 250 µg of the protein in FCA and then boosted with 250 µg of the protein in FIA on day 21. On day 35 after the primary immunization serum samples were collected. Mice were immunized intraperitoneally with 125 µg of the protein in FCA and boosted with the same dose on day 23. On day 30 after the primary immunisation serum samples were collected.

The titration of an antiserum for the binding of antibodies to a protein can be quantified by a solid phase radioimmunoassay (RIA) in which the wells of a microtitre plate are coated with the protein and then serial dilutions of the antibody solution are added to the series of wells. After washing away the unbound antibodies the bound antibodies are detected using a highly labelled specific reagent for the first antibodies, such as protein A from Staphylococcus aureus of affinity purified IgG specific for the first antibodies.

The proteins which were used to coat the microtitre plates were either the fusion proteins purified from lysates of E. coli as described in Example 8, or the P.195 purified by monoclonal antibody affinity chromatography from extracts of P. falciparum infected red

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cells as described by Holder and Freeman (1984b,
supra).

The antigens were diluted to 20 µg/ml in 0.05M NaHCO₃,
pH 9.6 and 50 µl of this solution was added to each
5 wall of a 96 well PVC microtitre plate (Dynatech Laboratories). After 90 minutes the plate was washed
thoroughly with phosphate-buffered saline supplemented
with 0.5% (v/v) Tween 40 and 0.2% (w/v) bovine serum
albumin (wash buffer). 50 µl of each serum dilution
10 was added to duplicate wells and after 30 minutes the
plate was washed for 10 minutes in wash buffer. Specific antibody was detected by addition of 50 µl of
125I-labelled protein A (1.5×10^5 cpm) for 30 minutes,
followed by extensive washing and determination of
15 bound radioactivity using a Packard PED gamma counter.

As can be seen from Table 1 rabbits immunized with the
fusion proteins containing P.195 sequences produced
antibodies which reacted with the purified P.195 in
the RIA and the polyvalent antiserum against P.195
20 contained antibodies which reacted with the fusion
proteins. In this instance, fusion protein 1 is the
product of the pPFc1028 EcoRI-Ndel fragment inserted
into trpE and fusion protein 2 is the product of the
pPFc1028 EcoRI-Hind III fragment inserted into trpE.

In Example 8 it was shown that the fusion proteins reacted with antibodies in the polyvalent anti-P.195 antiserum on Western blots. The antiserum raised against the fusion proteins reacted with the fusion proteins and with the purified P.195 protein, on Western blots.

The position of the processing fragments in the linear coding sequence was determined partially by immunoprecipitation from a detergent extract of ³⁵S-methionine labelled P. falciparum (Example 7). When the antisera against the fusion proteins were used to immunoprecipitate proteins from this extract, P.195 was recognised in each case. In addition the rabbit antiserum raised against protein coded by the pPFc1028 EcoRI-NdeI insert reacted predominantly with the 153,000 and 29,000 M_w fragments. The rabbit antiserum raised against the pPFc1028 EcoRI-Hind III insert reacted predominantly with the 42,000 M_w fragment.

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Table 1 Antibody Binding to Different Antigens by
Solid Phase RIA

^{125}I -Protein A (cpm) bound by antibodies
 in antisera at $\frac{1}{10}$ dilution

	Antigen	Normal Rabbit	Rabbit anti- P.195	Rabbit anti- Fusion Protein 1	Rabbit anti- Fusion Protein 2
9	P.195	161	6581	1959	1432
10	Fusion Protein 1	234	2007	10952	13291
	Fusion Protein 2	52	1093	3600	3416

CLAIMS:

1. A cloned DNA sequence corresponding to Figure 1 and encoding the P.195 protein of P. falciparum.
2. A DNA sequence according to Claim 1 possessing 5 one or more of the restriction sites as shown in Figures 2 and 3.
3. The coding sequence corresponding to the sequence from nucleotide 216 to nucleotide 5178 of a cloned DNA sequence corresponding to Figure 1 10 which encodes the P.195 protein of P. falciparum.
4. The coding sequence corresponding to the sequence from nucleotide 216 to nucleotide 5178 of a cloned DNA sequence corresponding to Figure 1 and encoding the P.195 protein of P. falciparum and possessing 15 one or more restriction sites as shown in Figures 2 and 3.
5. The coding sequence corresponding to the sequence from nucleotide 273 to nucleotide 5178 of the cloned DNA sequence corresponding to Figure 1 20 encoding the P.195 protein of P. falciparum.
6. The coding sequence corresponding to the sequence from nucleotide 273 to nucleotide 5178 of the

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cloned DNA sequence corresponding to Figure 1
encoding the P.195 protein of P. falciparum
and possessing one or more restriction sites
as shown in Figures 2 and 3.

5 7. A fragment of the coding sequence corresponding
 to the sequence from nucleotide 273 to nucleo-
 tide 5178 of the cloned DNA sequence correspond-
 ing to Figure 1 which encodes the P.195 protein
 of P. falciparum, said fragment encoding a poly-
10 peptide of molecular weight of 83000 derived
 from the amino terminus of the P.195 protein
 of P. falciparum.

15 8. A fragment of the coding sequence correspond-
 ing to the sequence from nucleotide 273 to nucleo-
 tide 5178 of the cloned DNA sequence correspond-
 ing to Figure 1 which encodes the P.195 protein
 of P. falciparum, and possesses one or more of
 the restriction sites as shown in Figures 2 and
 3, said fragment encoding a polypeptide of mole-
20 cular weight of 83000 derived from the amino ter-
 minus of the P.195 protein of P. falciparum.

9. A fragment of the coding sequence corresponding
 to the sequence from nucleotide 273 to nucleo-
 tide 5178 of the cloned DNA sequence corres-

ponding to Figure 1 which encodes the P.195
protein of P. falciparum, said fragment encod-
ing a polypeptide of molecular weight of 153000
derived from the amino terminus of the P.195
protein of P. falciparum.

5

10. A fragment of the coding sequence corresponding
to the sequence from nucleotide 273 to nucleo-
tide 5178 of the cloned DNA sequence correspond-
ing to Figure 1 which encodes the P.195 protein
of P. falciparum and possessing one or more of
the restriction sites as shown in Figures 2 and
3, said fragment encoding a polypeptide of mole-
cular weight of 153000 derived from the amino
terminus of the P.195 protein of P. falciparum.

15

11. A fragment of the coding sequence corresponding
to the sequence from nucleotide 273 to nucleotide
5178 of the cloned DNA sequence corresponding to
Figure 1 which encodes the P.195 protein of P.
falciparum, said fragment encoding a polypeptide
of molecular weight of 153000 derived from the
20 amino terminus of the P.195 protein of P. falciparum.

12. A fragment of the coding sequence corresponding
to the sequence from nucleotide 273 to nucleotide

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5178 of the cloned DNA sequence corresponding to Figure 1 which encodes the P.195 protein of P. falciparum and possessing one or more of the restriction sites as shown in Figures 2 and 3, said fragment encoding a polypeptide of molecular weight of 42000 derived from the amino terminus of the P.195 protein of P. falciparum.

13. A vector containing a cloned DNA sequence corresponding to Figure 1 and encoding the P.195 protein of P. falciparum.

10

14. A vector containing a fragment of the coding sequence corresponding to the sequence from nucleotide 273 to nucleotide 5178 of the cloned DNA sequence corresponding to Figure 1 which encodes the P.195 protein of P. falciparum, said fragment encoding a polypeptide of molecular weight of 83000 derived from the amino terminus of the P.195 protein of P. falciparum.

15

15. A vector containing a fragment of the coding sequence corresponding to the sequence from nucleotide 273 to nucleotide 5178 of the cloned DNA sequence corresponding to Figure 1 which encodes the P.195 protein of P. falciparum, said fragment encoding a polypeptide of molecular weight of 42000 derived from the amino terminus of the P.195 protein of P. falciparum.

20

weight of 153000 derived from the amino terminus of the P.195 protein of P. falciparum.

16. A vector containing a fragment of the coding sequence corresponding to the sequence from nucleotide 273 to nucleotide 5178 of the cloned DNA sequence corresponding to Figure 1 which encodes the P.195 protein of P. falciparum, said fragment encoding a polypeptide of molecular weight of 42000 derived from the amino terminus of the P.195 protein of P. falciparum.

17. A host transformed by a vector containing a fragment of the coding sequence corresponding to the sequence from nucleotide 273 to nucleotide 5178 of the cloned DNA sequence corresponding to Figure 1 which encodes the P.195 protein of P. falciparum, said fragment encoding a polypeptide of molecular weight of 83000 derived from the amino terminus of the P.195 protein of P. falciparum.

18. A host transformed by a vector containing a fragment of the coding sequence corresponding to the sequence from nucleotide 273 to nucleotide 5178 of the cloned DNA sequence corresponding to Figure 1 which encodes the P.195 protein

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of P. falciparum, said fragment encoding a polypeptide of molecular weight of 153000 derived from the amino terminus of the P.195 protein of P. falciparum.

5 19. A host transformed by a vector containing a fragment of the coding sequence corresponding to the sequence from nucleotide 273 to nucleotide 5178 of the cloned DNA sequence corresponding to Figure 1 which encodes the P.195 protein of P. falciparum, said fragment encoding a polypeptide of molecular weight of 42000 derived from the amino terminus of the P.195 protein of P. falciparum.

10 20. A vaccine for inducing immunity to malaria comprising a polypeptide obtained from culturing a host transformed by a vector containing a fragment of the coding sequence corresponding to the sequence from nucleotide 273 to nucleotide 5178 of the cloned DNA sequence corresponding to Figure 1 which encodes the P.195 protein of P. falciparum, said fragment encoding a polypeptide of molecular weight of 83000 derived from the amino terminus of the P.195 protein of P. falciparum in association with a pharmaceutically

acceptable carrier.

21. A vaccine for inducing immunity to malaria comprising a polypeptide obtained from culturing a host transformed by a vector containing a fragment of the coding sequence corresponding to the sequence from nucleotide 273 to nucleotide 5178 of the cloned DNA sequence corresponding to Figure 1 which encodes the P.195 protein of P. falciparum, said fragment encoding a polypeptide of molecular weight of 153000 derived from the amino terminus of the P.195 protein of P. falciparum in association with a pharmaceutically acceptable carrier.

22. A vaccine for inducing immunity to malaria comprising a polypeptide obtained from culturing a host transformed by a vector containing a fragment of the coding sequence corresponding to the sequence from nucleotide 273 to nucleotide 5178 of the cloned DNA sequence corresponding to Figure 1 which encodes the P.195 protein of P. falciparum, said fragment encoding a polypeptide of molecular weight of 42000 derived from the amino terminus of the P.195 protein of P. falciparum in association with a pharma-

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aceutically acceptable carrier.

23. A vaccine for inducing immunity to malaria comprising a polypeptide obtained from culturing a host transformed by a vector containing a cloned DNA sequence corresponding to Figure 1 and encoding the P.195 protein of P. falciparum.

5

24. A polypeptide encoded by the fragment of the coding sequence corresponding to the sequence from nucleotide 273 to nucleotide 5178 of the cloned DNA sequence corresponding to Figure 10 which encodes the P.195 protein of P. falciparum, said fragment encoding a polypeptide of molecular weight of 153000 derived from the amino terminus of the P.195 protein of 15 P. falciparum.

15

25. A polypeptide encoded by the fragment of the coding sequence corresponding to the sequence from nucleotide 273 to nucleotide 5178 of the cloned DNA sequence corresponding to Figure 20 which encodes the P.195 protein of P. falciparum, said fragment encoding a polypeptide

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of molecular weight of 42000 derived from
the amino terminus of the P.195 protein of
P. falciparum.

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Patented JAN 13 1992

Patent No. 25993

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TATATATATATACATATGTGTAAGGAAAATAATTGAATAATATTAAAATTAGTTATG
10 20 30 40 50 60

ATGTAATAATAATTTTATTATAAAAATAAGGCTAATGTAATAATGCAAAAATAATGTA
70 80 90 100 110 120

TACATATTTGCTAAGTCATATTTAAATTATTAACCTATTTATTATTATTATTTT
130 140 150 160 170 180

M K I I F F L C S
ATTTATATATATTATTAGCTTAATTCAATAATGAAGATCATATTCTTTATGTT
190 200 210 220 230 240

F L F F I I N T Q C V T H E S Y Q E L V
CATTCTTTTTTATTATAAAACACAAATGTGTAACACATGAAAGTTATCAAGAACTTG
250 260 270 280 290 300

K K L E A L E D A V L T G Y S L F Q K E
TCAAAAAAACTAGAAGCTTAGAAGATGCACTATTGACAGGTTATAGTTATTCAAAAGG
310 320 330 340 350 360

K H V L N E G T S G T A U T T S T F G S
AAAAAAATGGTATTAAATGAAGGAACAAGTGGAACAGCTGTTACAACTAGTACACCTGGT
370 380 390 400 410 420

K G S V A S G G S G S V A S G G S V A
CAAAGGGTTCAAGTTGCTTCAGGTGGTCAGGTGGCTCAGTTGCTTCAGGTGGCTCAGTTG
430 440 450 460 470 480

S G G S V A S G G S V A S G G S G N S R
CTTCAGGTGGCTCAGTTGCTTCAGGTGGCTCAGTTGCTTCAGGTGGTCAGGTAATTCAA
490 500 510 520 530 540

R T N P S D N S S D S D A K S Y A D L K
GACGTACAAATCCTTCAGATAATTCAAGTATTGATTGCTAAATCTTACGCTGATTAA
550 560 570 580 590 600

H R V R N Y L L T I K E L K Y F Q L F D
AACACAGAGTACGAAATTACTTGTAACTATCAAAGAACTCAAATATCCTCAACTCTTG
610 620 630 640 650 660

L T N H M L T L C D N I H G F K Y L I D
ATTTAACTAATCATATGTAACTTTGTGTATAATATTATGGTTCAAATATTTAATTG
670 680 690 700 710 720

FIG.1A

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Patented JAN 13 1992

Patent No. 25993

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G Y E E I N E L L Y K L N F Y F D L L R
ATGGATATGAAGAAATTAAATGAATTATTATATAAACTTTATTTGATTTATTA
730 740 750 760 770 780

A K L N D U V C A N D Y C O I P F N L K I
GAGCAAAATTAAATGATGTATGTGCTAATGATTATTGTCAAATACCTTCAATCTAAAA
790 800 810 820 830 840

R A N E L D U V L K K L V F G Y R K F L D
TTCGTGCAAAATGAATTAGACGTACTTAAACCTGTGTTGGATATAGAAAACCATTA
850 860 870 880 890 900

N I K D N V G K M E D Y I K K N K K T I
ACAATATTAAGATAATGTAGGAAAAATGGAAGATTACATTAAACATTAACCA
910 920 930 940 950 960

E N I N E L I E E S K K T I D K N K N A
TAGAAAATATAATGAATTAAATTGAAGAAAAGTAAGAAAACATTGATAACAAAGAATG
970 980 990 1000 1010 1020

T K E E E K K K L Y Q A Q Y D L S I Y N
CAACTAAAGAAGAAGAAAAAAATTATACCAAGCTCAATATGATCTTCTATTTACA
1030 1040 1050 1060 1070 1080

K Q L E E A H N L I S V L E K R I D T L
ATAACAAATTAGAAGAACATAATTAAAGCGTTTAGAAAAACGTATTGACACTT
1090 1100 1110 1120 1130 1140

K K N E N I K E L L D K I N E I K N P P
TAAAACAAATGAAAACATTAAAGGAATTACTTGATAAGATAAAATGAAAATAAAAATCCCC
1150 1160 1170 1180 1190 1200

P A N S G N T P N T L L D K N K R I E E
CACCGGCCAATTCTGGAAATACACCAAATACTCTCCTGATAAGAACAAAAATCGAGG
1210 1220 1230 1240 1250 1260

H E K E I K E I A K T I K F N I D S L F
ANACACGAAAAAGAAAATAAAAGAAAATTGCCAAAACTATTAATTTAATATTGATAGTTAT
1270 1280 1290 1300 1310 1320

T D P L E L E Y Y L R E K N K N I D I S
TTACTGATCCACTTGAATTAGAATACTATTAAAGAGAAAAAAATAAAAATATTGATATAA
1330 1340 1350 1360 1370 1380

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FIG.1B

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Patented JAN 13 1992

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A K V E T K E S T E P N E Y P N G V T Y
GTGCAAAAGGTTGAAACAAAGGAATCAACTGAACCCAAATGAATATCCAAATGGAGTTACTT
1390 1400 1410 1420 1430 1440

P L S Y N D I N N A I L N E L N S F G D L
ATCCTTTGTCATATAACGATATTAACAATGCTTAAATGAACCTTAATTCTTTGGTGATT
1450 1460 1470 1480 1490 1500

I N P F D Y T K E P S K N I Y T D N E R
TAATTAATCCATTTGATTATACAAAAAGAACCAAGTAAAAACATATATACTGATAATGAAA
1510 1520 1530 1540 1550 1560

K K F I N E I K E K I K I E K K K I E S
GAAAAAAATTCAATAATGAAATTAGGAAAAAAATTAAAATAGAAAAAAATTGAAAT
1570 1580 1590 1600 1610 1620

D K K S Y E D R S K S L N D I T K E Y E
CTGATAAAATCTTACGAAGACAGATCTAAGTCTTAAATGATATAACAAAGAATATG
1630 1640 1650 1660 1670 1680

K L I H E I Y D S K F N N N I D L T N F
AAAAATTCTTAAATGAAATTATGATAGCAAAATTCAATAATAGATTAACTANTT
1690 1700 1710 1720 1730 1740

E K M H G K R Y S Y K V E K L T H F N T
TCGAAAAAATGATGGTAAAAGATATTCAATAAGTTGAGAAACTTACACACCTAATA
1750 1760 1770 1780 1790 1800

F A S Y E N S K H N L E K L T K A L K Y
CTTTGCACTCTATGAAAATTCTAAACATAATCTTGAAGTTAACAAAGCTCTTAAAT
1810 1820 1830 1840 1850 1860

M E D Y S L R N I U V E K E L K Y Y K N
ATATGGAAGATTATTCTTAAAGGAATATAGTAGTTGAAAAAGAATTAAATATTATAAAA
1870 1880 1890 1900 1910 1920

L I S K I E N E I E T L V E N I K K D E
ATTAAATAAGCAAAATAGAAAATGAGATTGAAACATTAGTTGAAAATATTAAAAAGATG
1930 1940 1950 1960 1970 1980

E Q L F E K K I T K D E N K P D E K I L
AAGAACAGCTTTGAAAAAAATTACTAAAGACGAAAATAACCAAGATGAAAAATT
1990 2000 2010 2020 2030 2040

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FIG.1C

Patented JAN 13 1992

Patent No. 25933

ANTHONY ARTHUR HOLDER ET. AL.
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E V S D I V K V Q V Q K V L L M N K I D
TAGAAAGTATCTGACATTGTAAGTACAGTTCAAAAGTTTATTAATGAAACAAAATTG
2050 2060 2070 2080 2090 2100

E L K K T Q L I L K N V E L K H N I H V
ACGAATTAAAAAGACTCAATTGATTAAAAATGAGAATTAAAACATAATACATG
2110 2120 2130 2140 2150 2160

P N S Y K Q E N K Q E P Y Y L I V L K K
TTCCCATTCTTACAAACAGAAAATAAGCAAGAACCTTATTATTGTGTTGAAAA
2170 2180 2190 2200 2210 2220

E I D K L K V F M P K V E S L I N E E K
AAGAAAATTGATAAATTAAAAGTGTTCATGCCATAAGGAGAATCATTGATAAAATGAAAGAAA
2230 2240 2250 2260 2270 2280

K N I K T Q G Q S D N S E P S T E G E I
AAAAAAACATAAAAACACAAAGGTCAATCGGATAATTGGAAACCATCAACCGAAGGGAGAAA
2290 2300 2310 2320 2330 2340

T G Q A T T K F G Q Q A G S A L E G D S
TAACAGGACAAAGCAACTACAAAACCTGGACAAAGCAGGATCTGCTTAGAAGGAGATT
2350 2360 2370 2380 2390 2400

V Q A Q A Q E Q K Q A Q P F V F V F V F
CACTACAAGCACAAGCACAAGAACAAAAACAGCACAAACCAACCACTACAGTAC
2410 2420 2430 2440 2450 2460

E A K A Q U F T P F A P V N N K T E R V
CAGAAAGCAAAAGCACAAAGTCCCACACCCACAGCAGTAAATAATAAAACTGAAAATG
2470 2480 2490 2500 2510 2520

S K L D Y L E K L Y Q F L N T S Y I C H
TTTCCAAATTAGATTATCTGAAAAATTATATCAATTAAACTTCATATATATGTC
2530 2540 2550 2560 2570 2580

K Y I L V S H S T M N E K I L K Q Y K I
ACAAATATATTTGGTTACACTCAACTATGAACGAAAAGATATTAAAACAATATAAAA
2590 2600 2610 2620 2630 2640

T K E E E S K L S S C D P L D L L F N I
TTACAAAGGAGGAAGAACAAATTAAAGTTATGATCCATTAGACTTATTGTTAATA
2650 2660 2670 2680 2690 2700

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FIG.1D

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Patented JAN 13 1992

Patent No. 25993

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Q N N I P V M Y S M F D S L N I V Y H N
TACAAAATAACATACTGTAATGTATTCTATGTTGATAGCTAAACATAAGTTTATCACA
2710 2720 2730 2740 2750 2760

Y L W V Y E K E I G Y V F I L L M E I Y
ACTATTTATGGGTTATGAAAAAGAAAATGGTTATGTATTATATTACTTATGGAAAATT
2770 2780 2790 2800 2810 2820

E K E M V C N L Y K L K D N D K I K N L
ATGAAAAGAAAATGGTTGTAATTATATAAACTTAAGGATAATGACAAAATTAAAAATT
2830 2840 2850 2860 2870 2880

L E E A K K V S T S V K T L S S S S M Q
TATTAGAGGAAGCGAAAAAAAGTATCCACATCTGTAAAAACCTTCAAGTTCATCAATGC
2890 2900 2910 2920 2930 2940

F L S L T F Q D K F E V S A N D D T S H
AACCATTATCATTAACACCTCAGGATAACCCGAAGTAAGTGCACATATTGAGTCTTCATCAATGC
2950 2960 2970 2980 2990 3000

S T N L N N S L K L F E N I L S L G K N
ATTCTACAAATTGAAATAATAGTTAAATTATTTGAAAACATATTGAGTCTTGAAAGAAA
3010 3020 3030 3040 3050 3060

K N I Y R E L I G Q K S S E N F Y E K I
ACAAAAATATACCAAGAATTAAAGGTCAAAAAAGTAGTGAACACTTTATGAAAAGA
3070 3080 3090 3100 3110 3120

L K D S D T F Y N E S F T N F V K S K A
TATTAAGAGATAGTGATACTTATAATGAAATCTTACAAATTGTAATCTAAAG
3130 3140 3150 3160 3170 3180

D D I N S L N D E S K R K K L E E D I N
CTGATGATATTAAATTCTATTGAAATGATGAATCAAGGAAAGAAATTAGAAGAAGATATTA
3190 3200 3210 3220 3230 3240

K L K K T L Q L S F D L Y N K Y K L K L
ATAAAATTAAAAAAACTTACAGTTATCTTGTGATTATAATAAAATATAAAATTAAAAT
3250 3260 3270 3280 3290 3300

E R L F D K K K T V G K Y K M Q I K K L
TAGAAAAGATTATTGATAAAAAGAAAACAGTTGGTAATATAAAATGCAAATTAAAAC
3310 3320 3330 3340 3350 3360

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FIG.1E

Patented JAN 13 1992

Patent No. 25992

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T L L K E Q L E S K L N S L N N P K H V
TTACTTTATTAAGAACAAATTAGAATCAAATTGAATTCACTTAATAACCCAAAGCATG
3370 3380 3390 3400 3410 3420

L Q N F S U F F N K K K E A E I A E T E
TATTACAAAACCTTTCTGTTTCTTTAACAAAAAAAAGAAAGCTGAAATAGCAGAAAATG
3430 3440 3450 3460 3470 3480

N T L E N T K I L L K H Y K G L U K Y Y
AAAACACATAGAAAACACAAAATATTGAAACATTATAAAGGACTGTAAATATT
3490 3500 3510 3520 3530 3540

N G E S S P L K T L S E E S I Q T E D N
ATAATGGTGAATCATCTCCATTAAAAACTTTAAGTGAAGAATCAATTCAAACAGAAAGATA
3550 3560 3570 3580 3590 3600

Y A S L E N F K V L S K L E G K L K D N
ATTATGCCAGTTAGAAAACCTTTAAAGTATAAGTAATTAGAAGGAAAATTAAAGGATA
3610 3620 3630 3640 3650 3660

L N L E K K K L S Y L S R G L H H L I A
ATCTAAATTAGAAAAGAAAAATTATCATACTTATCAAGAGGTTTACATCATTTAATTG
3670 3680 3690 3700 3710 3720

E L K E V I K N K N Y T G N S F S U N N
CTGAATTAAAAGAAAGTAATAAAAATATAACAGGTAAATTCTCCAGCGTAATA
3730 3740 3750 3760 3770 3780

T D U N N A L E S Y K K F L P E G T D V
ATACGGATGTTAACATGCATTAGAATCTTACAAAAAATTCTCCCAGAAGGAACAGATG
3790 3800 3810 3820 3830 3840

A T U V S E S G S D T L E Q S O P K K P
TTGCAACAGTTGTAAGTGAAGAGTGGATCCGACACATAGAACAAAGTCACCAAAGAAC
3850 3860 3870 3880 3890 3900

A S T H V G A E S N T I T T S Q H V D D
CAGCATCAACTCATGTAGGAGCAGAGTCTAACACACATAAACATCACAAAATGTCGATG
3910 3920 3930 3940 3950 3960

E V D D V I I U L I F G E S E E D Y D D
ATGAAGTAGATGACGTAATCATAGTACTCATATTGAGAATCCGAAGAAGATTATGATG
3970 3980 3990 4000 4010 4020

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FIG. 1F

25993

Patented JAN 13 1992

Patent No. 25993

ANTHONY ARTHUR HOLDER ET. AL.
CLONING OF DNA FOR PROTOZOAL ANTIGENS

Filed: February 21, 1985

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L G Q V V T G E A V T T S V I D N I L S
ATTAGGACAAGTAGTAAACAGGAGAACGAGTAACCTACTTCGTAATTGATAACATACTT
4030 4040 4050 4060 4070 4080

K I E N E Y E V L Y L K P L A G U Y R S
CTAAAATTGAAAATGAATATGAGGTTTATATTAAACCTTAGCAGGTGTTATAGAA
4090 4100 4110 4120 4130 4140

L K K Q L E N N U M T F N U N U K D I L
GTTAAAAAAACAATTAGAAAATAACGTTATGACATTAAATGTTAAGGATATT
4150 4160 4170 4180 4190 4200

N S R F N K R E N F K N U L E S D L I F
TAAATTCACTGATTAAATAACGTGAAAATTCAAAAATGTTTAGAATCAGATTAAATC
4210 4220 4230 4240 4250 4260

Y K D L T S S N Y V V K D P Y K F L N K
CATATAAGATTTAACATCAAGTAATTATGTTGTCAGATCCATATAAAATTCTTAATA
4270 4280 4290 4300 4310 4320

E K R D K F L S S Y N Y I K D S I D T D
AAGAAAAAGAGATAAAATTCTTAAGCAGTTATAATTATTAAGGATTCAATAGATAACGG
4330 4340 4350 4360 4370 4380

I N F A N D V L G Y Y K I L S E K Y K S
ATATAAATTGCAAAATGATGTTCTGGATATTATAAAATATTATCCGAAAAATAATAAAT
4390 4400 4410 4420 4430 4440

D L D S I K K Y I N D K Q G E N E K Y L
CAGATTAGATTCAATTAAAAATATATCAACGACAAACAGGTGAAAATGAGAAAATACC
4450 4460 4470 4480 4490 4500

P F L N N I E T L Y K T V N D K I D L F
TTCCCTTTAAACAAATTGAGACCTTATATAAAACAGTTATGATAAAATTGATTAT
4510 4520 4530 4540 4550 4560

V I H L E A K V L N Y T Y E K S N V E V
TTGTAATTCAATTAGAAGCAAAAGTTCTAAATTATACATATGAGAAATCAGTAGAAG
4570 4580 4590 4600 4610 4620

K I K E L N Y L K T I Q D K L A D F K K
TTAAAATAAGAACCTTAATTACTAAAAACATTCAAGACAAATTGGCAGATTAAAN
4630 4640 4650 4660 4670 4680

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FIG. 1G

Patented 11/13/1992

Patent No. 25909

ANTHONY ARTHUR HOLDER ET. AL.
CLONING OF DNA FOR PROTOZOAL ANTIGENS

Filed: February 21, 1985

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N N N F V G I A U L S T D Y N H H H L L
AAAATAACAAATTCTGGAAATTGCTGATTTATCAACAGATTAAACCTATAAAGCTTAT
4690 4700 4710 4720 4730 4740

T K F L S T G H V F E H L L K S V L S N
TGACAAAGTTCTTAGTACAGGTATGGTTTTGAAAACCTTGCTAAACATCGTTTATCTA
4750 4760 4770 4780 4790 4800

L L D W K L A R Y V K H F T T P H R K K
ATTTACTTGATTGGAAACTTGCAGGTATGTTAACATTTCAACACACCAATGCGTAAGA
4810 4820 4830 4840 4850 4860

T H I Q Q S S G C F R H L D E R E E C K
AAACAAATGATCCAACAGAGTTCTGGATGTTAGACATTAGATGAAAGAGAAGAAATGTA
4870 4880 4890 4900 4910 4920

C L L N Y K Q E G S K C V E N S N P T C
AATGTTTATTAAATTACAAACAGAGGTAGTAAATGTGTTGAAATTCACCTACTT
4930 4940 4950 4960 4970 4980

N E N N G G C D A D A K C T E E D S G S
GTAACGAAAATAATGGTGGATGTGATGCAGATGCCAAATGTACCGAAGAAGATTAGGTA
4990 5000 5010 5020 5030 5040

N G K K I T C E C T K P D C Y P L S H V
GCAACGGAAAAGAAAATCACATGTGAATGTTACTAACCTGATTGTTATCCACTTTGATGG
5050 5060 5070 5080 5090 5100

I F C S S S N F L G I S F L L I L H L I
TAATTTCTGCAGTTCTCTAACTCTTAGGAATATCATTCTTATTAACTCATGTTAA
5110 5120 5130 5140 5150 5160

L Y S F I
TATTATACAGTTTCATTAAAGATGTTAGGAGTTAAATATGTTACCTTAATTTTTTT
5170 5180 5190 5200 5210 5220

TTTTTTTTTTAAATATATATATATATTAAATATATATATATAAATATTACATAA
5230 5240 5250 5260 5270 5280

TATATATATATATTAGTTTACAGGAATAGTGTATTTAGTCATGTTCAAAATATAT
5290 5300 5310 5320 5330 5340

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FIG. 1H

25993

Patented May 13, 1992

Patent No. 25993

ANTHONY ARTHUR HOLDER ET. AL.
CLONING OF DNA FOR PROTOZOAL ANTIGENS
Filed: February 21, 1985

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TAAAAAAATTATAAATATTATAAATAAAAAAGGGGGGGGGATTATAACTTATAAAT
5350 5360 5370 5380 5390 5400

TTATACATTATACATATATATATATATTTTTTTCTCTTTCTTTCAAGTTCTAT
5410 5420 5430 5440 5450 5460

TTTATATTTATATATAGATTAAATAAAAACCTTTAAATAAATAAAAGTACGTAAT
5470 5480 5490 5500 5510 5520

TTTAATATATATATATATATAATATATAATATATATTTTATTATTTATATG1
5530 5540 5550 5560 5570 5580

ATAATATATTTACATATATTATAATATATATATTTTTTACGCATACATAAAAAG
5590 5600 5610 5620 5630 5640

CATTTTTTTTTATAAACATTCCAAACAATTATAAAATAACTTTAATAATAACATTAA
5650 5660 5670 5680 5690 5700

TTTTTATTTTTTTTAAAGAGAGATTATTCA
5710 5720 5730 5740 5750 5760

FIG.1I

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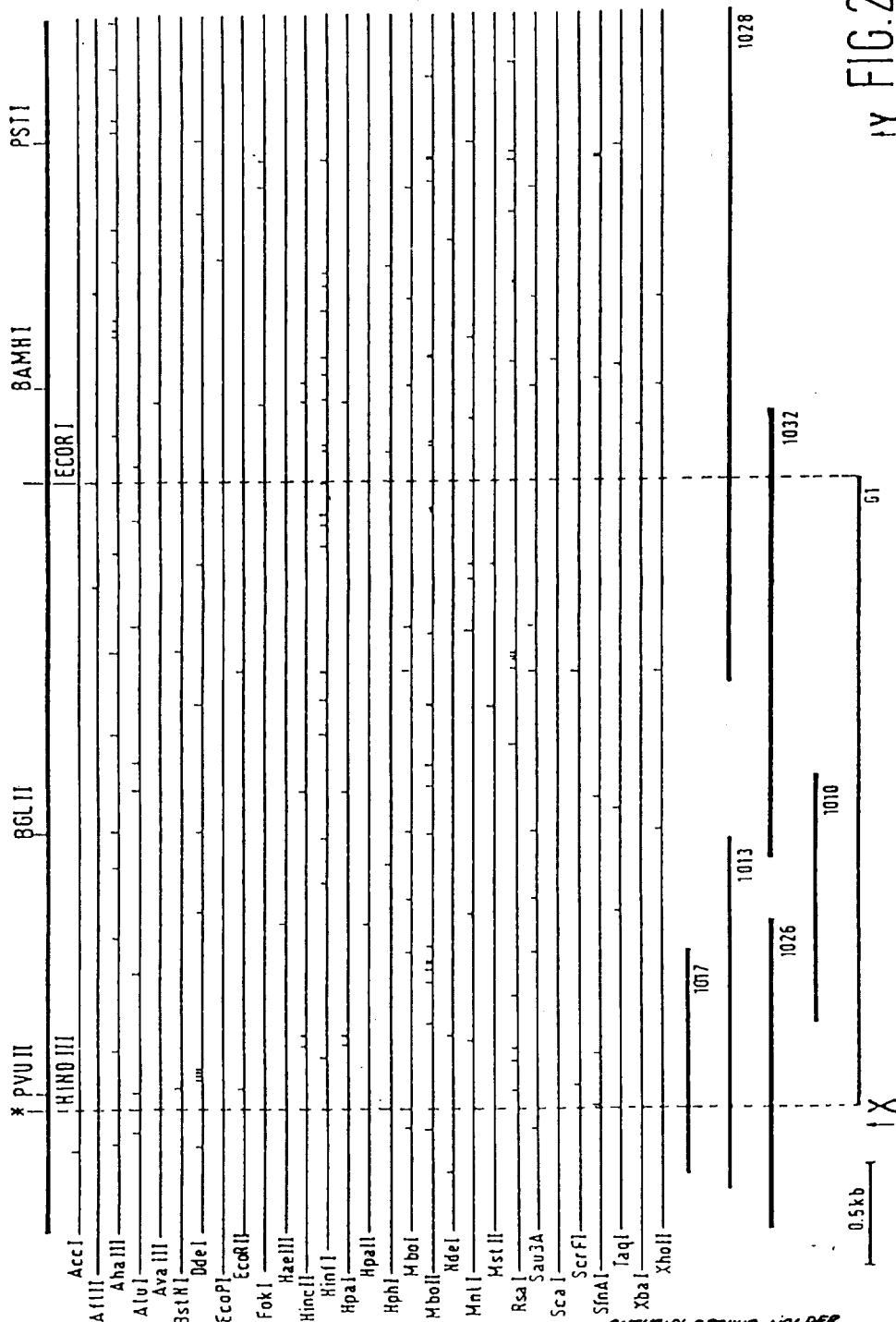
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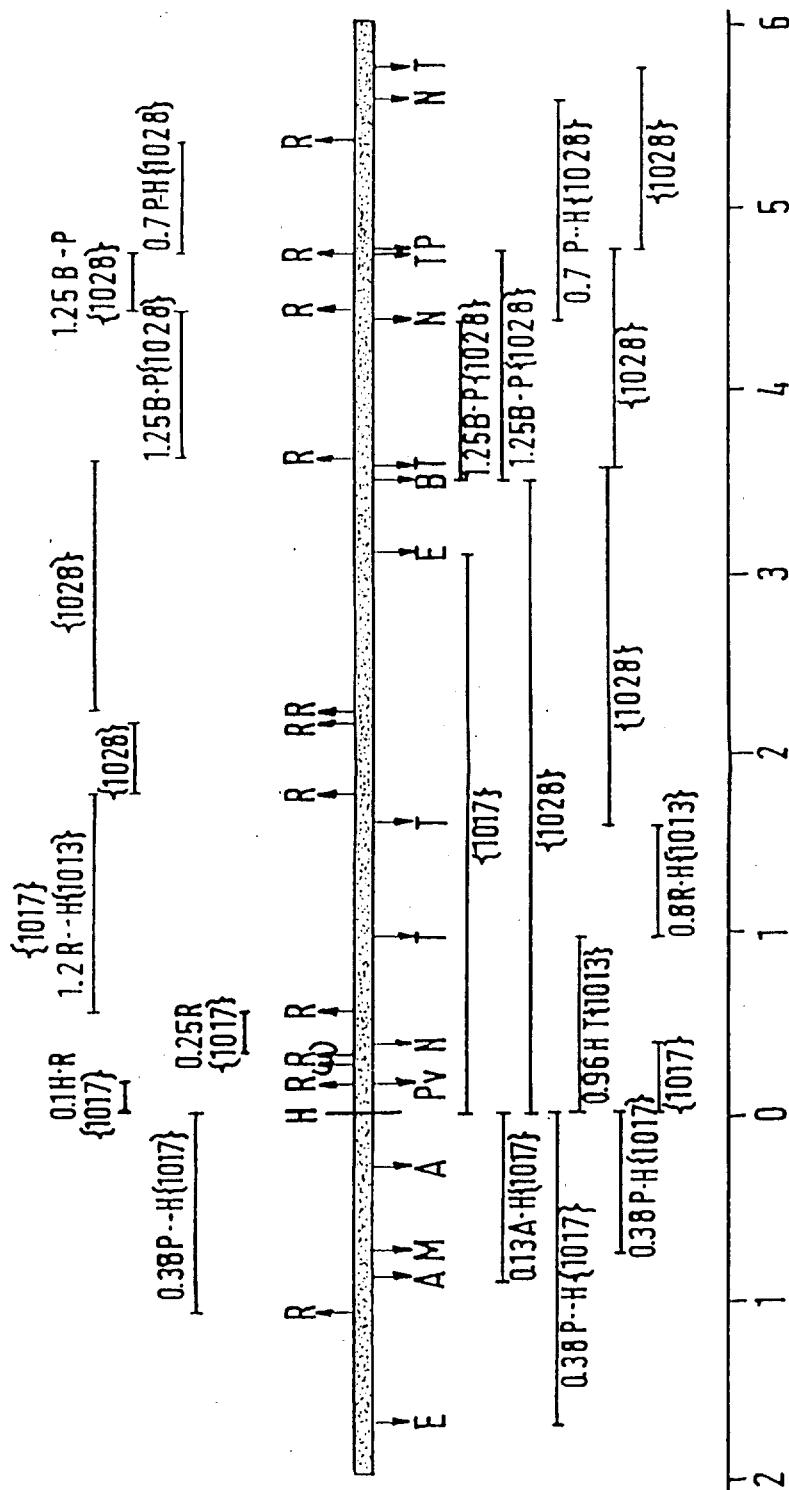
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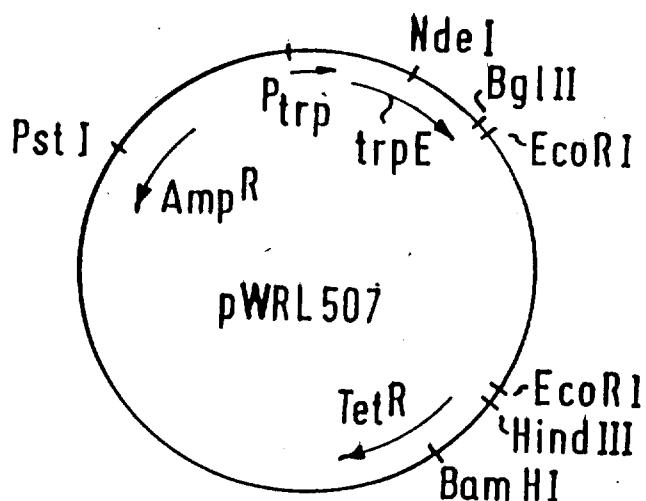
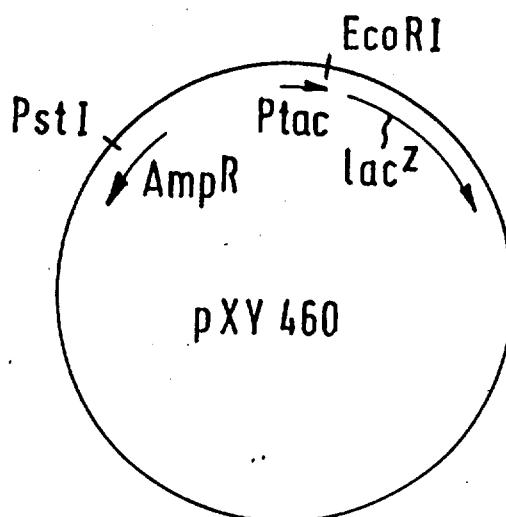


FIG.4



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